North Carolina

Division of Soil and Water Conservation

Community Conservation Assistance Program

Stormwater Best Management Practice Design Manual

NCDENR

NC STATE UNIVERSITY

Prepared By:

Biological and Agricultural and Engineering Department

North Carolina State University

William F. Hunt, PhD, PE
Assistant Professor and Extension Specialist

Jon M. Hathaway, EI
Extension Associate

Ryan A. Smith, PE
Extension Associate

Table of Contents

1.0 Introduction 6
1.1 Introduction to the Community Conservation Assistance Program 6
1.2 The CCAP Best Management Practice Design Manual 7
2.0 Introduction to Stormwater 7
2.1 Definition of Stormwater 7
2.2 Effects of Urbanization 8
2.3 Stormwater BMPs 10
3.0 General Stormwater BMP Design Considerations 11
3.1 The First Flush 11
3.2 Connected Imperviousness 12
3.3 The Simple Method 12
3.4 Peak Flow 15
3.4.1 Storm Intensity 16
3.4.2 Runoff Coefficient 17
3.5 Diversion Berms 17
3.6 Determining Outlet Location and Size 18
3.6.1 Determining Outlet Location 18
3.6.2 Determining Outlet Size 18
3.6.3 Outlet installation 19
3.7 Riparian Buffer Considerations 19
3.8 General Soils Discussion 20
3.8.1 Information from Soil Surveys 21
3.8.2 Information from Site Investigation 21
3.9 Information on Water Table Depth 23
4.0 General Stormwater BMP Considerations 23
4.1 Avoid Concentrated Flow 23
4.2 Multiple Property Owners 24
4.3 General Information Matrix for Backyard Stormwater BMPs 25
5.0 Backyard Rain Garden Design 25
5.1 Overview of Practice 25
5.2 Selection of this practice over others 25
5.3 Rain Garden Design 26
5.3.1 Rain garden siting 26
5.3.2 Determine watershed and impervious area draining to BMP 26
5.3.3 Rain garden sizing 27
5.3.4 Rain garden bottom topography 28
5.3.5 Plant selection 28
5.3.6 Inlet protection and pretreatment 29
5.3.7 Outlet design 31
5.4 Rain Garden Maintenance 31
6.0 Backyard Wetland Design 32
6.1 Overview of Practice 32

6.2 Selection of this practice over others....33
6.3 Backyard Wetland Design....34
6.3.1 Determining wetland watershed characteristics....34
6.3.2 Backyard wetland sizing....34
6.3.3 Backyard wetland inlet considerations....35
6.3.4 Backyard wetland outlet considerations....36
6.3.5 Backyard wetland plants....36
6.3.6 Drought tolerant wetland....38
6.4 Backyard Wetland Construction....39
6.4.1 Laying out the wetland....39
6.4.2 Digging the wetland....40
6.4.3 Planting the wetland....42
6.5 Backyard Wetland Maintenance....43
7.0 Cistern Design....44
7.1 Overview of Practice....44
7.2 Selection of this practice over others....46
7.3 Cistern Design....46
7.3.1 Determining Cistern Watershed Characteristics....46
7.3.2 Cistern sizing....47
7.3.3 Additional Cistern Components....48
7.3.4 Outlet structure....49
7.4 Cistern Construction....49
7.4.1 Preparing the soil base....49
7.4.2 Preparing the gutter downspout....50
7.4.3 Preparing the gutter downspout....50
7.4.4 Setting the cistern into place....51
7.4.5 Final cistern construction considerations....52
7.5 Cistern Maintenance....52
8.0 Vegetated Swales....53
8.1 Overview of Practice....53
8.2 Determining Site Constraints....54
8.3 Depth and Velocity Calculations....55
8.4 Simplified Triangular Swale Design....57
8.4.1 Adjusting Manning's equation for simplified triangular swale design....57
8.4.2 Simplified triangular swale design process....59
8.5 Construction Guidance....60
8.6 Maintenance....61
9.0 Impervious Removal....61
9.1 Overview of Practice....61
9.2 Selection of this practice over others....62
9.3 Carrying Out Impervious Removal....62
10.0 Permeable Pavement....62
10.1 Overview of Practice....62
10.2 Selection of this practice over others....64
10.3 Permeable Pavement Design....65

10.3.1 Initial Soil Analysis Field Test 65
10.3.2 Soil Analysis Lab Test 66
10.3.3 Concrete Edging 66
10.3.4 Gravel Base 67
10.3.5 Permeable Pavement Sizing Criteria 68
10.4 Permeable Pavement Construction 68
10.4.1 Soil excavation 69
10.4.2 Gravel base 69
10.4.3 Concrete edging 70
10.4.4 Permeable pavement installation 70
10.5 Permeable Pavement Maintenance 70
11.0 References: 72

1.0 Introduction

1.1 Introduction to the Community Conservation Assistance Program

The population distribution of North Carolina is becoming more urban and suburban, causing the North Carolina Division of Soil and Water Conservation to address nonpoint source pollution from these non-agricultural lands. In the summer of 2006, a survey was distributed to all districts to inventory their level of interest in best management practices on urban, suburban and rural lands. Many districts completed surveys about their needs for this program, and they requested over $6.5 million for local projects. Division staff used the survey responses to develop two grant applications for program funding; both were approved at 100% funding. In addition, the Soil and Water Conservation Commission received authorizing legislation to establish the Community Conservation Assistance Program through Session Law 2006-78, partially due to the strong support of District Supervisors.

The Community Conservation Assistance Program (CCAP) supports the installation of water quality best management practices on non-agricultural lands. This program is an innovative approach to controlling water quality impacts caused by stormwater runoff. Through locally-led conservation, the Division of Soil and Water Conservation (DSWC) and Soil and Water Conservation Districts (SWCD) have been successful in implementing voluntary agricultural BMPs, which have addressed many water quality parameters. The CCAP is intended to operate under the same guidance and accountability as the NC Agriculture Cost Share Program and achieve the same successes.

CCAP will focus its efforts on retrofitting stormwater BMPs on existing land uses; it will not be used to assist new development sites to meet state and federal stormwater mandates. Soil and Water Conservation Districts have the technical expertise to install stormwater BMPs and a successful history of promoting voluntary conservation practices. The program will give the Districts the structure and financial assistance to carry out this mission. CCAP will encourage local governments, individual landowners, and businesses to incorporate stormwater BMPs within their landscape where BMPs were not required by regulation. The economic incentive, 75% of average installation costs, will encourage voluntary conservation.

Since this is a grant funded program, only districts participating in the surveys will receive an allocation. The maximum amount of assistance per practice is limited to $50,000. To see which districts will be implementing CCAP BMPs through these grants, refer to the map below (Figure 1.1). Other Districts are implementing these BMPs through funding sources they have secured on their own. The goal of the DSWC is to seek additional funding sources, including recurring state appropriations, to offer this program statewide in the future. The

Community Conservation Assistance Program is expected to be an asset in addressing current stormwater pollution issues within North Carolina.

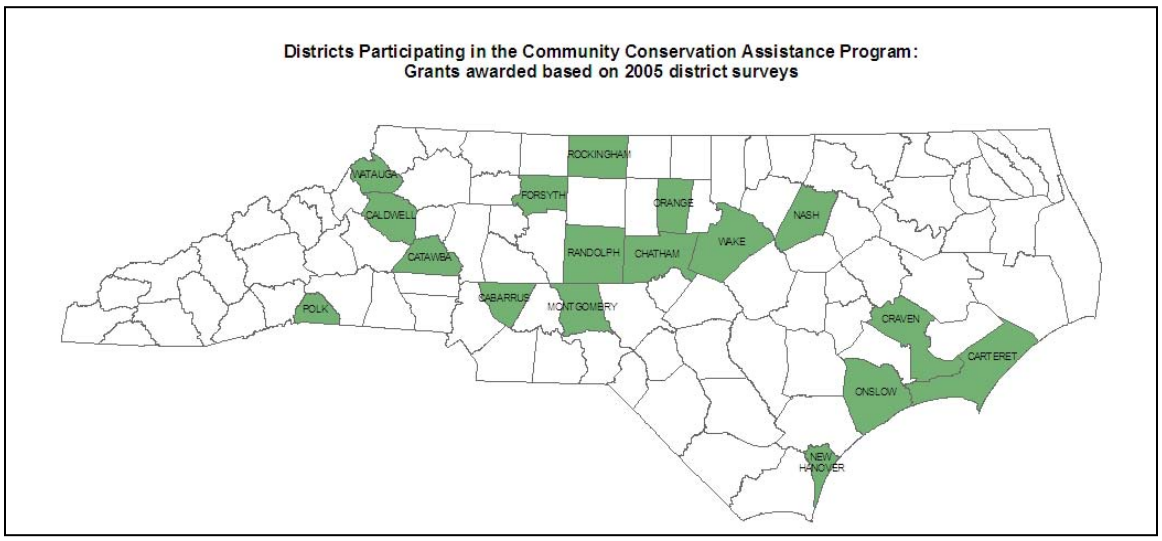


Figure 1.1 Districts Participating in the Community Conservation Assistance Program

1.2 The CCAP Best Management Practice Design Manual

The purpose of the CCAP Stormwater Best Management Practice (BMP) Design Manual is to be a resource for soil and water conservation district staff in siting, selecting, designing, installing, and maintaining stormwater BMPs. This manual is intended to educate staff members in order to implement effective stormwater practices while efficiently distributing funds throughout participating districts.

As part of the CCAP, North Carolina State University Biological and Agricultural Engineering Department (BAE) has also prepared a document entitled, "Stormwater BMP Costs," for use by employees of the Soil and Water Conservation Division (Hathaway and Hunt, 2006). This resource was produced so proper cost estimates can be prepared by district staff. Proper BMP cost estimates will lead to efficient allocation of cost share funds. This document should be referenced in conjunction with the CCAP Stormwater Best Management Practice Design Manual to fulfill the intentions of the program.

2.0 Introduction to Stormwater

2.1 Definition of Stormwater

Stormwater is produced immediately following a rainfall event or as a result of snowmelt. When a rainfall event occurs, there are four potential fates for the precipitation: (1) Some infiltrates into the soil, (2) a portion is taken up by plants and released to the atmosphere (called transpiration), (3) a fraction evaporates to the atmosphere and (4) the remainder of the rainfall runs off land surfaces and

impervious areas. This final fraction is stormwater (North Carolina Division of Water Quality: Stormwater Unit).

2.2 Effects of Urbanization

North Carolina contains communities that are considered among the best places to live in America; as a result, the state's growth rate is consistently one of the highest in the country. The resulting urban influx affects many facets of the state's infrastructure–more cars drive our roads, more children enroll in our schools, more people create higher wastewater discharges, and more development necessitates stormwater runoff controls. How does urbanization affect stormwater runoff? Roads, parking lots, sidewalks, homes, and offices replace the natural–and permeable–landscape. Rainfall that once soaked into vegetated ground is now "available" for stormwater runoff. As more surfaces become impermeable, water simply moves across them. Impermeable surfaces connect to form a "stormwater superhighway" that allows runoff to reach streams more quickly (Figure 2.1).

Figure 2.1 Stormwater runoff in a highly urbanized watershed

There are many affects of this increase in impermeable area: (1) more stormwater reaches streams because there is less opportunity for it to infiltrate into the ground; (2) peak flows increase because the "stormwater superhighway" transports runoff from large areas rapidly; (3) velocities in the stream increase, causing a larger erosion potential; and (4) baseflow is lower during dry weather due to a lack of infiltration into the underlying groundwater. An area with natural ground cover loses 40% of the annual rainfall it receives to evapotranspiration, 25% of the annual rainfall goes into the shallow groundwater, 25% of the rainfall goes into deep infiltration, and 10% runs off. When impervious areas cover 35%

to 50% of a similar watershed, only 35% of the annual rainfall is lost to evapotranspiration, 20% of the annual rainfall goes into the shallow groundwater, 15% goes into deep infiltration, and 30% runs off (Leopold, 1968). Figures 2.2 and 2.3 illustrate the impact of urbanization (Donaldson, 2007).

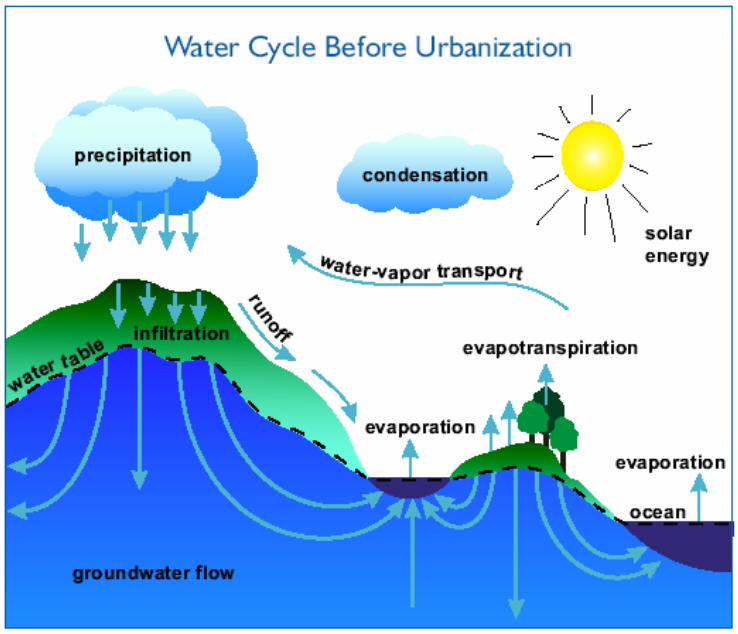


Figure 2.2 Watershed hydrology prior to urbanization

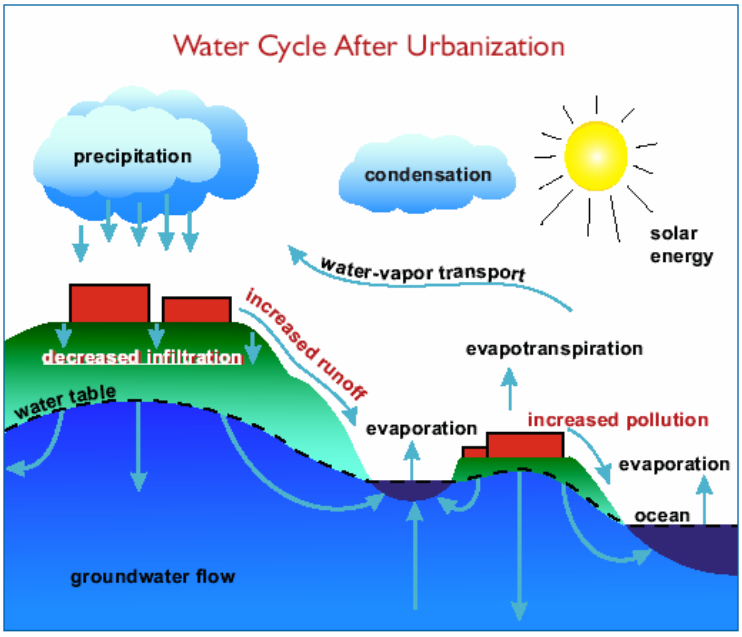


Figure 2.2 Watershed hydrology after urbanization

Using traditional analyses such as the Natural Resources Conservation Services' stormwater model, TR-55, or the U.S. Army Corps of Engineers' many versions of HEC, it can be shown that peak flows alone can increase by up to five-fold from pre- to post-development conditions. The public knows this effect of urbanization as flooding. While an increase in stormwater runoff is an easily seen result of urbanization, there are many less visible water quality impacts associated with development. Erosion and sedimentation have long been recognized as water quality concerns. Although the North Carolina legislature passed laws to curb sediment pollution in 1973, sediment remains the number one pollutant of N.C. waters. In addition, metals and chemicals from vehicles and industries pollute stormwater runoff in increasing amounts. Under forested conditions, these pollutants would only be found in trace amounts. Likewise, nutrients are found in the urban environment in a variety of forms, one such form being fertilizer. Fertilizer contains nutrients for plants to grow, but excess fertilizer or fertilizer that is inadvertently applied to pavement harms water quality. Even if proper amounts of fertilizer are applied, nutrients can enter our streams in other ways, including atmospheric deposition, wildlife and pet waste, and septic system malfunction. There are numerous ways to reduce pollutant loadings, including source reduction–such as proper application of fertilizer and correctly maintaining septic systems. Structural devices can also help curb this problem. This manual will provide design guidance for several structural Best Management Practices (BMPs) that can be constructed to treat runoff and thereby reduce the amount of pollution entering streams.

2.3 Stormwater BMPs

An urban stormwater BMP is believed to be a "best" way of treating or limiting pollutants in stormwater runoff. It can be as simple as applying the proper amount of fertilizer to a home lawn or as complex as building an engineered structure such as a stormwater wetland. Each BMP has certain conditions under which it will function properly. The pollutants to be treated, the size of watershed, the imperviousness of the watershed, the local water table, and the amount of available land for the practice all influence the selection of a BMP. Some of the BMPs are relatively well known and researched, while others are in their infancy. This document will focus on BMPs that can be installed in small scale settings, such as individual residences and small businesses. The stormwater BMPs that will be discussed in this document are: backyard rain gardens, backyard wetlands, cisterns, grassed swales, impervious surface removal, and permeable pavements. Each of these BMPs can be valuable in treating the stormwater leaving a given watershed. Guidance on BMP selection (based on site conditions) will be discussed in detail in this document.

3.0 General Stormwater BMP Design Considerations

3.1 The First Flush

The term “first flush” has become common nomenclature in the stormwater management field. The concept behind this term is that pollutants that have collected on impervious surfaces will wash off during the first part of a storm event. Essentially, the first portion of a given rain event will “flush” the impervious surface of its pollutants, resulting in stormwater runoff that contains more pollutants than runoff produced later in the storm. This concept was adopted by many in the stormwater management field, who theorized that if the first half inch of runoff (the first flush) could be captured and treated by a stormwater practice, that 90% of the pollutants leaving the site would be treated by the stormwater practice (Schueler, 2000). Of course, one half of an inch of runoff is not produced by one half of an inch of rainfall. Some water is stored in depressions in roadways, lawns, and other places; and some infiltrates into the watershed’s grassed and forested areas. Thus, capturing the runoff associated with 1 inch of rainfall was previously considered the standard for capturing the first flush. However, because rainfall patterns vary throughout North Carolina, it was questionable that 1-inch of rainfall corresponded to the first flush in all areas of North Carolina.

A study was performed by BAE for NCDENR to evaluate the first flush (or water quality event) in various locations throughout North Carolina (Bean, 2005). For the basis of this study, the water quality storm event was defined as the event size (in depth) which 90% of all storms are equal to or less than. Essentially, if a stormwater practice is sized to capture 90% of all rain events, it will theoretically be able to treat at least 90% of the pollutants from a given watershed. Prior to the study, the water quality storm was considered to be 1 inch in all areas of North Carolina excluding CAMA counties. In CAMA counties, the water quality storm was considered 1.5 inches. Figure 3.1 shows a map of the CAMA counties in North Carolina.

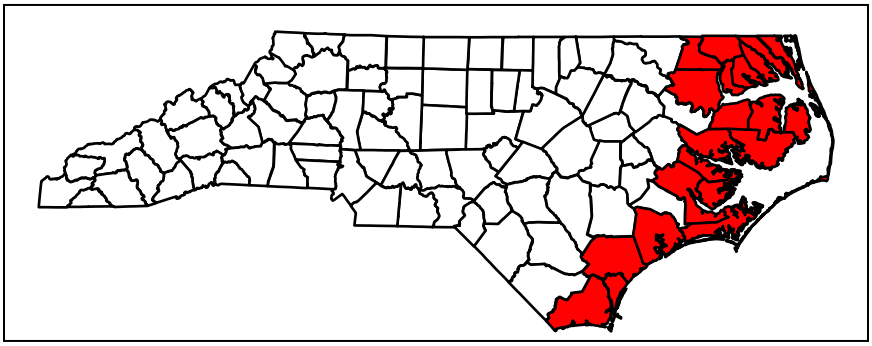


Figure 3.1 Map of CAMA counties in North Carolina

Thirty years of rainfall data were analyzed from 9 locations in North Carolina. For most of North Carolina, capturing approximately 1 inch of rainfall would only result in capturing 80% of all the rainfall that fell on a given watershed. Likewise, in CAMA counties, 1.5 inches would result in capturing approximately 80% of all the rainfall. Because of the premise that the majority of pollution is carried in the earlier portions of the storm, it was assumed that at least 90% of pollution would be transported by the runoff produced by 80% of the rainfall. NCDENR considered these values to be acceptable based on this assumption, so the stormwater design standards remained the same. There are a few supporting studies in literature for this (Flint and Davis, 2007), but the theory has not been proven completely (Sansalone and Cristina, 2004)

3.2 Connected Imperviousness

The idea of impervious areas was discussed above in section 2.2; however, not all impervious areas substantially contribute to stormwater runoff in a given watershed. Impervious areas that immediately drain to a drainage system (such as a pipe or swale) are considered to be “connected impervious” areas and more readily produce runoff within urban environments. For example, a rooftop that drains to a gutter which drains directly unto a nearby street (as can be found in many cities) and into the street drainage would be considered “connected impervious.” Conversely, if a rooftop drained onto a lawn where runoff would sheet flow across the grass, the rooftop would not be considered connected impervious as it is does not immediately drain into any stormwater conveyance system. Runoff from non-connected impervious areas is routed to some pervious area where it has a chance to infiltrate. As a rule of thumb, if a rooftop or pavement is allowed to sheet flow for at least 30 feet before it re-concentrates (e.g. forming a swale or spilling into a drop inlet), it may be considered a non-connected impermeable surface.

3.3 The Simple Method

The water quality storm can easily be used to calculate the anticipated volume of runoff that will leave a given residence or small business through the application of the simple method (Schueler, 1987). The required information is as follows: (1) area that will be draining to the proposed BMP location in square feet, (2) the percentage of the drainage area that is impervious, and (3) the desired depth of rainfall targeted for capture (normally the water quality event). The simple method is described in equations 1 and 2 below.

Equation 3-1: Calculate Runoff Coefficient

$$Rv = 0.05 + (0.009 * I)$$

Equation 3-2: Calculate Runoff Volume

$$V = Rv * A * (P/12)$$

Where:

Rv = Runoff Coefficient (fraction of rainfall that will produce runoff)
I = Connected impervious percentage in watershed (%)
V = Volume of runoff (ft^3)
A = Area that drains to BMP (ft^2)
P = Depth of storm to be captured (normally water quality event) (in)

Figures 3.2, 3.3, 3.4 and 3.5 use the simple method to calculate the volume of water that can be expected from a given watershed, these values are calculated using water quality events of either 1 inch or 1.5 inches (as defined in figure title).

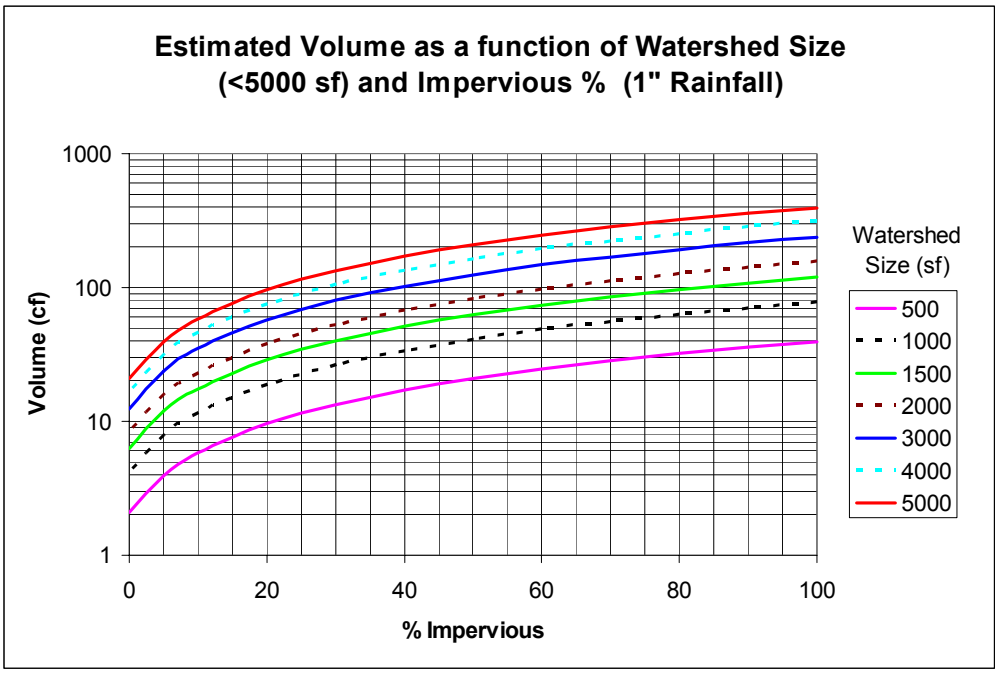


Figure 3.2 Estimated runoff volumes from various watersheds for 1-inch rainfall

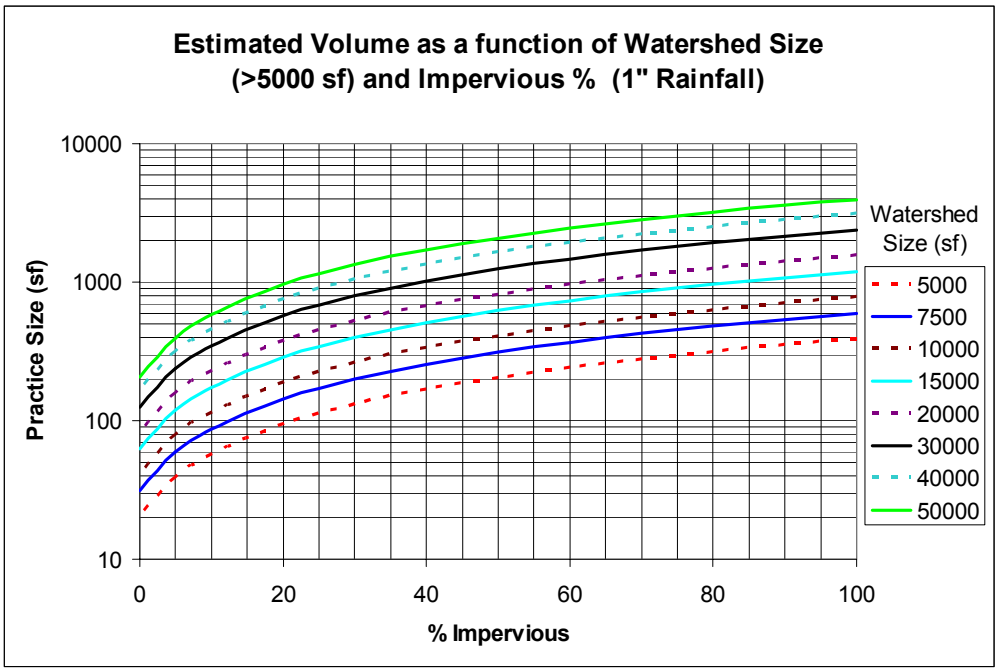


Figure 3.3 Estimated runoff volumes from various watersheds for 1-inch rainfall

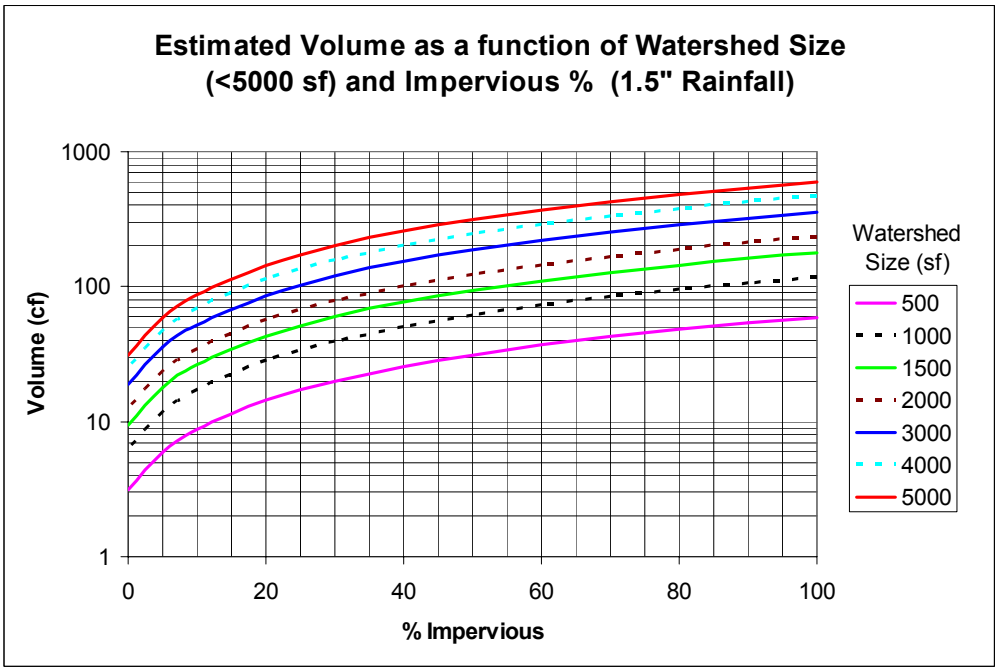


Figure 3.4 Estimated runoff volumes from various watersheds for 1.5-inch rainfall

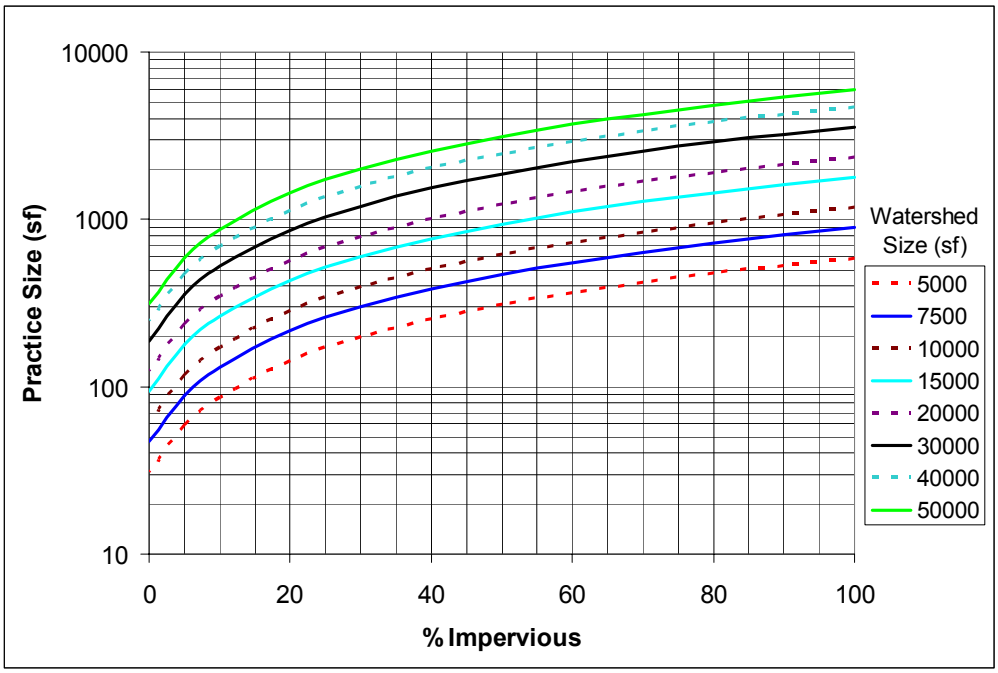


Figure 3.5 Estimated runoff volumes from various watersheds for 1.5-inch rainfall

3.4 Peak Flow

Determining the peak flow leaving a watershed during a design storm is important when designing many stormwater BMPs. The peak flow is simply the largest flow that leaves the watershed through the course of a storm event. Figure 3.6 shows a sample flow vs. time relationship and the associated peak flow. The depth of rain that falls throughout the event can be observed on the right side of the graph.

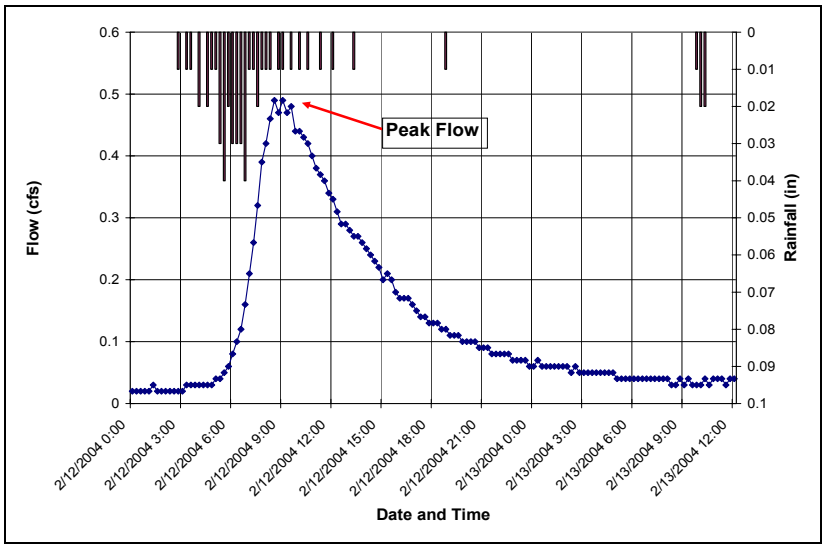


Figure 3.6 Peak Flow Illustration

The peak flow is used to determine the proper size of conveyances such as swales and drainage pipes and can also be used to determine the proper size of high flow overflow devices. Peak flow can be calculated easily using the rational method (Bedient and Huber, 1992). The rational method is a simple model used to estimate the peak flow from a given watershed. For applications such as backyard stormwater BMPs, where small, highly impervious watersheds will be treated, the rational method offers a somewhat coarse, but adequate estimate of peak flow. The rational method is as follows:

Equation 3-3: Rational Method

$$Q = C \times I \times A$$

Where:
Q = Peak flow (ft^3/s)
C = Runoff Coefficient (dimensionless) – varies based on land use
A = Watershed area being treated (acres)
I = Intensity of storm event to be captured (in/hr)

(Note: There are 43,560 ft^2 in 1 acre)

3.4.1 Storm Intensity

The rational method is highly adaptable to various land uses, storm events, and watershed characteristics. For the purpose of this manual, some generalizations can be made to simplify the calculation. Rainfall intensity varies throughout the course of a storm. For small watersheds (those being treated by the backyard BMPs constructed as part of this program) stormwater from the far end of the connected impervious area does not have a long distance (typically 100's but not 1000's of feet) to travel to the BMP; thus, the time it takes stormwater to reach the BMP from all parts of the watershed is short. With these watershed characteristics, the peak flow from the watershed is likely to be produced by the most intense part of the storm. A short duration of high intensity rainfall is the most intense part of the storm, thus, a the amount of rainfall that falls during the most intense 5 minutes of the storm will be chosen as the intensity used in the rational method calculation. Table 3.1 shows the 5-minute peak intensity for various North Carolina cities for the 2, 5, 10, and 25-year storm events. Data from the city closest to the proposed BMP location can be used (Table 3.1) or further information can be gathered for a specific city by visiting the National Weather Service's - Hydrometeorological Design Studies Center (http://hdsc.nws.noaa.gov/hdsc/pfds/orb/nc_pfds.html)

Table 3.1 Peak Intensity (in/hr) for Various Storm Events (5-minute duration)

Location	2 - year	5 - year	10 - year	25 - year
Asheville	4.8	5.8	6.5	7.4
Charlotte	5.6	6.6	7.2	8.0
Greensboro	5.4	6.2	6.8	7.4
Winston-Salem	5.3	6.2	6.8	7.6
Fayetteville	6.1	7.1	7.9	8.9
Raleigh	5.6	6.5	7.2	7.9
Durham	5.6	6.5	7.2	7.9
Wilmington	7.4	8.6	9.7	10.9
Elizabeth City	6.1	7.0	7.9	9.0
Greenville	6.2	7.1	8.0	9.1

Taken from the National Weather Service

3.4.2 Runoff Coefficient

Although it is assumed that the BMPs implemented as part of the CCAP will treat watersheds that are primarily impervious (rooftops, driveways, parking lots), there will likely be other land uses associated with each watershed. Landscaped areas, lawns, and other pervious areas are likely in each watershed. The rational method is versatile enough to account for both the impervious and pervious areas of each watershed.

Runoff coefficients (C) vary per type of land use. In an effort to simplify the process of determining a composite C value that can be applied to a given watershed, a C value of 0.95 should be applied to all impervious areas, and a C value of 0.25 should be applied to all pervious areas. Equation 3-4 can be used to determine a C value that can be applied to the whole watershed.

Equation 3-4: Determine the Composite Runoff Coefficient

$$C = [((\text{Impervious Area}) \times 0.95) + ((\text{Pervious Area}) \times 0.25)]/\text{Watershed Area}$$

3.5 Diversion Berms

Diversion berms are earthen structures that are designed to intercept stormwater and direct it to the BMP. They can increase the effectiveness of the BMP by allowing it to treat a larger watershed. The sideslopes of the berm should not be graded steeper than 2:1. The height of the berm does not need to exceed 1 foot. The diversions can be covered with grass or mulch depending on the landscape and the expected runoff velocities in the diversion. Erosion control blanket should be used for cover while vegetation is being established.

3.6 Determining Outlet Location and Size

3.6.1 Determining Outlet Location

Close attention should be paid to where the water from a stormwater BMP exits a given property. During small rain events, depending on soil conditions, all the stormwater produced in a small watershed may be retained in the BMP. However, the BMP will also experience larger rain events that overload it with stormwater. During these events, the stormwater BMP will fill to capacity and spill into the adjoining area. Special care should be taken to ensure that the area to which the excess stormwater spills is able to convey the stormwater safely to a nearby drainageway (such as a culvert or swale).

The easiest way to allow excess stormwater to leave a property is to direct it into the existing drainage pathways. For instance, if a roof drain leads to a swale which routes the water off the property, a BMP could be placed in the path of the swale, whereby small amounts of runoff are retained and treated and stormwater from larger storms flows out of the BMP and continues down the swale.

Other drainage conveyances can be used to safely allow large stormwater volumes to leave a property. Yard inlets, swales, and ditches can all be used for this purpose. In some cases a swale must be constructed between the BMP and the closest natural drainageway to allow proper draining of the system. More information on swales is available in section 8.0.

When earthen berms are used to retain stormwater (a common practice in rain garden and backyard wetland design) there is opportunity for the berm to erode if the BMP fills to capacity and spills over the retention berm. In these cases, it is good practice to design and protect a spillway for the additional stormwater. An opening in the berm can be constructed where the stormwater will be conveyed out of the system. A piece of pretreated lumber, with a rectangular notch cut in it, can be installed in the berm in this opening so the stormwater passes over a stable edge instead of over the easily eroded earthen berm. This lumber acts as a weir to spread the flow, thus reducing velocities. More information on BMP outlet design and construction is given in Sections 3.6.2 and 3.6.3.

3.6.2 Determining Outlet Size

The outlet weir rectangular notch (described above in Section 3.6.1) should be sized such that the notch is not overtopped during a 10-year storm event. This means that the weir notch must be long enough to allow the peak flow associated with the 10-year storm to pass without the water rising high enough that the top of the board is reached. To determine the appropriate length of weir notch to pass the 10-year storm, the weir equation can be applied. The weir equation is as follows:

Equation 3-5: Weir Equation

$$Q = C_w \times L \times H^{1.5}$$

Where:
Q = Flow (ft^3/s) – *Use peak flow from 10-year event*
C_w = Weir Coefficient (dimensionless) – *Use 3.0*
L = Length of Weir (ft)
H = Height of Water Over Top of Weir (ft) – *Use 0.5 feet*

The flow that should be passed is the flow associated with the 10-year event as determined using the rational method (Section 3.4). The weir coefficient is set to 3.0 and the height of the water over the top of the weir should be no higher than 6 inches (0.5 feet) so the water will not flow over the containment berm. Thus, the only unknown in the equation is the length of the weir. This equation can be rearranged to solve for the weir length:

Equation 3-6: Weir Equation

$$L = Q \div (C_w \times H^{1.5})$$

Sample 10-year peak flow calculations for various watershed scenarios are shown in Appendix A. Included is a required weir length for each watershed scenario.

3.6.3 Outlet installation

Appendix B shows a diagram of a wooden weir structure that could be used for an outlet control structure on large systems. For any type of outlet used, concentrated flows should only pass over a structure or undisturbed and vegetated soil. All wooden weir structures should be tied into the underlying soils. Soils filled around structures should be compacted and protected.

3.7 Riparian Buffer Considerations

Many regulations have been implemented to improve the quality of surface waters in North Carolina, including the riparian buffer rules detailed by the North Carolina Division of Water Quality in the "Redbook" of surface waters and wetlands standards (Administrative Code 15A NCAC 02B .0100, .0200 & .0300). These rules state that a 50 foot riparian buffer should be maintained around surface waters in the Tar-Pamlico Basin, Neuse River Basin, the main stem of the Catawba River, and in the Randleman Lake watershed; all these water bodies being nutrient sensitive. The purpose of these rules is to make use of the

inherent ability of riparian buffers to remove nutrients and other pollutants from stormwater runoff. These riparian buffer rules can impact the function and siting of a backyard stormwater BMP.

When siting a backyard BMP in one of the nutrient sensitive watersheds described in the NCDWQ Redbook, a measurement should be made perpendicular to the stream from the stream bank towards the area being considered for a BMP. No part of the BMP should be located within this 50-foot boundary running along the stream bank. Additionally, backyard swales can not be constructed in the riparian buffer. Only existing swales can be utilized to route water through the riparian buffer.

The riparian buffer rules not only include a requirement to maintain a 50-foot buffer along the stream bank, they also require that stormwater released into the buffer be done so in a diffuse manner. This means that in systems where water will be collected and dispersed through an outlet (wetlands, bioretention areas, etc.) the outlet should be designed to spread the water out as it enters the riparian buffer. No newly constructed channel should be used to convey the water into the buffer, instead, a large weir or berm can be used. The North Carolina Division of Water Quality – 401/404 Wetlands Unit should be contacted for additional information should a newly constructed drainage way be necessary. General level spreader guidance is found in Hathaway and Hunt, 2006 (Appendix C), and on-line via the North Carolina Division of Water Quality – Wetlands and Stormwater Branch (http://h2o.enr.state.nc.us/ncwetlands). Avoiding the installation of CCAP projects in areas adjacent to riparian buffers is generally recommended. If a project is located in a watershed with protected riparian buffers, the BMP discharge should be routed into any existing drainage ways if at all possible.

3.8 General Soils Discussion

Stormwater BMPs are impacted significantly by the soil in which they are constructed. Therefore, it is important to know which soil types are present at a given location before designing or constructing a stormwater BMP. Backyard Stormwater BMPs that rely heavily on infiltration (rain gardens and permeable pavement) must contain soils that will drain at most within 24 hours of a rain event, further details are provided later in this document. In North Carolina, the presence of clay precludes using soils from many parts of the state as the underlying soil for rain gardens and permeable pavement (As discussed in section 10.2, the need for infiltration in the underlying soils of permeable pavement prohibits its use in locations other than the Coastal Plain or Sandhills). Conversely, BMPs that require saturated soils to maintain BMP function and plant vitality (backyard wetland) require that water be easily accessible to plant roots via the water table or that poorly drained soils at the site will hold the captured stormwater long after a rain event (Section 6.0). When a site is

evaluated for BMP implementation, determining the soil type at the site can be performed by collecting information from soil surveys and, most importantly, from field reconnaissance.

3.8.1 Information from Soil Surveys

Division of Soil and Water Conservation staff should be familiar with the soil survey of their particular county. This soil survey provides some understanding of the type(s) of soils present at the site being considered for BMP installation. Once the soil that is present at the site (in situ soil) is identified, the staff member should observe the detailed description of the soil series in the soil survey. This description will give some detail as to the common location of a given soil in the county landscape and will give some description of what type of soil is present in each soil horizon in the soil series. *This information should only be used to gather preliminary data on a particular site*. A site investigation will be needed to verify the information gathered in the soil survey. In general, the soils will be classified as either well draining or poorly draining. The soil survey will also provide an indication of the expected seasonal high and low water table.

Generally, the soil types that are present from the soil surface to 36 inches below the soil surface are the most crucial for backyard BMP siting. If the soils in this range (0 – 36 inches deep) mostly consist of sand or loam, they may be suitable for backyard bioretention areas. If the soils in this range consist primarily of sandy soils, they may also be suitable for permeable pavement areas (only install in Coastal Plain or Sandhills). Lastly, if the soils in this range consist primarily of clay, they are potentially suitable for backyard wetlands.

3.8.2 Information from Site Investigation

Soil classifications gathered from a soil survey should *never be used exclusively* to determine which type of soil is present at a given site. A site investigation will be needed to verify that the soil on site is suitable for a given BMP. The first step in this investigation is to talk to the property owner about the condition of the proposed location immediately following a rain event. If the area remains wet or saturated 1.5 days after a rain event, it is likely at least somewhat poorly drained.

Additional information can be gathered by digging a hole in the location of the proposed BMP that is approximately 2-foot deep, or to the depth of the bottom of the proposed BMP, whichever is deeper. As the hole is being dug, the soil should be observed for signs that it is a wetland soil. Wetland soils are commonly grey with ribbons of brown (Figure 3.7 and 3.8). If wetland soils are identified within 1 foot of the surface at a given site, the site is likely poorly drained. A detailed description of wetland soils is available in Vepraskas (1999).

Figure 3.7 Brown ribbons in wetland soil

Figure 3.8 Brown ribbons in wetland soil (close)

The last evaluation that should be used during the site investigation is a simplified soil infiltration test. This is a test to check the permeability of the soils being evaluated for BMP suitability. A hole should be dug using an auger or spade, approximately 1 foot below the expected bottom of BMP. The newly dug hole should be filled with water (Figure 3.9). Monitor how quickly the hole drains and use this information to select the appropriate BMP. Table 3.3 shows a range of outcomes from the simplified soil infiltration test and the resulting BMP that is suggested based on the results. More information will be presented on these BMPs in sections 5 and 6. This drainage rate is particularly important for plant selection and bottom grading of the practice.

Figure 3.9 Simplified soil infiltration test

Table 3.2 Selection Chart for Soils with Moderate Infiltration

Time For 2-Foot Hole to Drain	BMP Selection
½ day or less	Standard Rain Garden
½ day to 1½ days	Zoned Rain Garden*
1½ days to 4 days	Drought tolerant wetland**
4 days or more	Standard wetland

* More information on the Zoned Rain Garden is available in Section 5.0
** More information on the Drought tolerant wetland is available in Section 6.0

3.9 Information on Water Table Depth

While the soil analysis is being performed at the proposed BMP location, the location of the seasonal high water table can be approximated. This is an evaluation of the highest consistent level that the water table reaches with respect to the ground surface during the year. As the soil is removed from the 2-foot hole that is dug at the site, the soils should be observed for signs of the seasonally high water table.

After the topsoil is excavated from the hole, the soil layers underneath provide some information regarding the location of the seasonally high water table. When soils are observed as gray or contain gray mottles (spots of gray color), this soil is likely in contact with the water table for extended periods of time. Thus, as the soil is being extracted from the hole, the seasonal high water table is likely to be at the depth at which these mottled soils are encountered. More information on determining the seasonal high water table is available in Richardson and Vepraskas (2001). Obviously, if groundwater is encountered as the hole is being dug, the site very likely has a high water table (Figure 3.10).

Figure 3.10 Obvious wet conditions in this location lead to selecting a backyard wetland as a stormwater BMP

If the seasonal high water table is found within 2 feet of the ground surface, the site is likely not a good candidate for certain stormwater BMPs (rain gardens, permeable pavement). If such conditions exist at a site, a backyard wetland is a more appropriate choice as a stormwater BMP; although, a seasonal high water table within 1-foot of the ground surface is more desirable for this BMP.

4.0 General Stormwater BMP Considerations

4.1 Avoid Concentrated Flow

Stormwater collects and concentrates very easily into depressions, swales, and natural runoff conveyances. Stormwater concentration can also occur as water

overflows from a backyard rain garden or wetland, or as water passes through a cistern that is already filled to capacity. This concentration can lead to erosion of berms, riparian buffers, lawns, or other ground cover.

If possible, backyard stormwater BMPs should be sited near or in the path of the current drainage way leading from the watershed being treated (Figure 3.6). The current drainage path can be utilized as a way to convey water away from the BMP should a storm occur that is larger than what the BMP can hold. If the drainage path is currently eroding, see section 8.0 for information on swale protection.

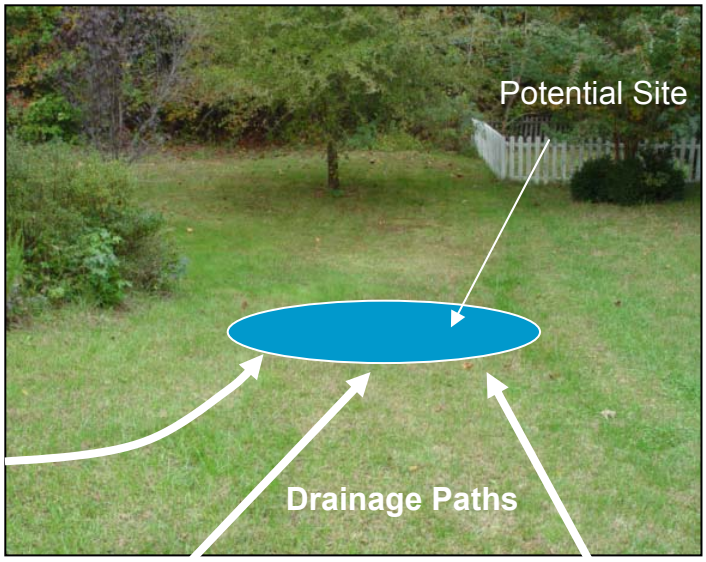


Figure 3.6 A low area in the drainage path provides a suitable location for a backyard BMP

4.2 Multiple Property Owners

Before a site is chosen for a backyard stormwater BMP, the property boundaries should be clearly defined by the SWCD staff member. This is to ensure that no part of the stormwater BMP is sited on property belonging to an individual not participating in the program. If a stormwater BMP is to be sited in such a way that multiple property owners will be impacted, all property owners should be contacted and should agree upon the project.

There is an additional concern in impacting adjoining property owners not participating in the program. Stormwater BMPs are designed to slow and capture stormwater as it leaves a given property, thus a pool of water can form as water slows and enters the stormwater BMP. This pool of water should not extend to a neighbor's property without consent. It should be noted, however, that downstream property owners usually benefit from their upslope neighbor's

installation of backyard BMPs, which bring about a potential reduction in flooding and erosion on the downstream owner's property.

4.3 General Information Matrix for Backyard Stormwater BMPs

5.0 Backyard Rain Garden Design

5.1 Overview of Practice

A rain garden (or bioretention area) is essentially a vegetated sand filter, and is designed so it quickly dries after rain events. These BMPs are depressions in the landscape, to which runoff is directed to be stored and infiltrate into the soil. A typical rain garden will not have ponded water for more than 12 hours, although a modified rain garden design can be used if water remains ponded between 12 and 36 hrs (1.5 days). Rain gardens are typically planted with a combination of trees, shrubs and perennials and then mulched. Grass can also be used as cover without other vegetation or along with trees, shrubs or perennials. Cover and layout of rain gardens can be very flexible to suit a given site.

Figures 5.1a Picture of rain garden installations in Caldwell County (left) and (b) Brunswick County (right), NC.

5.2 Selection of this practice over others

Rain Gardens offer an attractive, versatile and multi-functional option in stormwater treatment. They can sometimes be installed without the help of heavy equipment, although a small excavator would be beneficial in many cases. This will likely be one of the more commonly selected BMPs.

The proposed BMP location should not have a seasonal high water table closer than about 2.5 feet from the existing ground surface. A high water table will limit drainage from the system between rain events, increasing the likelihood of plant

loss due to wet conditions. The seasonal high water table can be evaluated using the method described in Section 3.8. The percolation rate of the soils should be tested as described in Section 3.7.2. When performing a simplified soil infiltration test, it is best to use several holes. Holes should extend approximately 1 foot below the anticipated depth of the proposed rain garden. Water should drain within 12 hours from each hole in order for the native soil to be acceptable for a traditional rain garden. If the water drains between 12 hours and 36 hours a modified rain garden design, called a zoned rain garden, could be used.

5.3 Rain Garden Design

5.3.1 Rain garden siting

There are a number of siting concerns regarding rain gardens. The soils must be suitable, as described in section 5.2. To avoid contact between the infiltrated stormwater and any building foundations, the rain garden should be located at least 10 feet away from any foundations. The rain garden should be at least 25 feet away from any septic system drain fields and 25 feet away from any well heads. It should not be upslope from wells and should be lateral to septic systems (not upslope or down slope). Utility lines should be located and marked prior to any excavation. For the best plant growth, the BMP should be located in an area that receives partial to full sun exposure.

The rain garden should be located where stormwater naturally drains or water should be routed to it. Avoid routing large areas to a new rain garden that would overload the existing drainage ways. This will ensure that the garden will intercept runoff during storm events and that overflows can be directed to existing drainage paths.

5.3.2 Determine watershed and impervious area draining to BMP

The first step in rain garden design is determining the watershed area that drains to the proposed rain garden site, which will contain some impervious area (typically between 10 and 40%). This impervious area will most likely consist of driveways and rooftops. In order to capture stormwater runoff from driveways and other associated parking areas, the drainage must flow to the proposed location. Rooftops normally are drained via gutters which may or may not drain to the proposed location. In this case; however, a 4 or 6-inch pipe can be used to route this water to the proposed location. After any modifications are considered (like routing rooftop drainage to the proposed area) the total watershed area and total impervious area draining to the proposed location can be calculated. Manual measurements taken with a tape measure will work well in determining the area draining to the BMP.

Figure 5.2 A rain garden's perimeter is laid out and a soil test is taken.

5.3.3 Rain garden sizing

Rain gardens should be sized to capture the first flush event. Once the amount of watershed and impervious area has been calculated, the Simple Method (Section 3.3) can be used to determine the volume of water that will enter the BMP during the first flush event. The depth of ponding in the bioretention cell can be selected based upon topography, available area and home owner preference. The approximate area needed for the rain garden is the runoff volume divided by the depth of ponding. Appendix D shows the results of such calculations and can be used to determine the BMP size based upon the percent of impervious area, watershed size and depth of ponding.

Figure 5.3 First flush events completely fill a rain garden to a ponding depth of 6 inches

5.3.4 Rain garden bottom topography

The topography of the bottom of the rain garden will largely be a function of the infiltration rate of the soil. The infiltration rate can be tested as described in Section 3.7.2. If the soil drains in 12 hours or less, the bottom of the rain garden can be essentially flat. If the soil drains between 12 and 36 hours, grade the bottom of the rain garden so that zones of varying bottom elevation exist. This will create areas where the flood pool depth is shallow and ponding time is shorter, which can help the survival of some bioretention plants (some of which cannot tolerate wet conditions for extended periods). Creating higher and lower elevation zones along with planting some plants on the banks of the bioretention cell can help ensure the survival of plants when drainage conditions are somewhat uncertain. Keep in mind that higher elevation zones take away from the storage volume of the garden and the area should be increased accordingly. This can be done by dividing the runoff volume by an average depth for the cell. For example, if 50% of the cell will be ponded 9 inches deep and 50% will be ponded 6 inches deep, the average depth is 7.5 inches. Shallow rain gardens take up more surface area than their deeper counter parts.

Figure 5.4 Mounding of soil allows certain rain garden plants to survive better in a zoned rain garden.

5.3.5 Plant selection

When the rain garden drains in less than 12 hours, the bioretention plant list in Appendix E can be used as a guide to plant selection. Grass can also be used in this case as an alternative to other vegetation or in combination with other vegetation. Warm season grass (e.g. Bermuda, Centipede, Zoysia) is recommended in much of the State, but cool season grass (Fescue, Kentucky 31) can be used in cooler climates or to match existing lawn. It may be necessary to re-seed the cell in the fall.

When the garden drains between 12 and 36 hours and the zoned rain garden is built (contains areas of high and low elevation), the plants in Appendix F should

be used. In each case it is good to use a variety of plants for aesthetic value and to improve the chances of plant survival. In the zoned system, place some plants in the base of the garden and others in higher areas and on the banks.

5.3.6 Inlet protection and pretreatment

It is a good practice to dissipate the energy of the inflow and to remove sediment from runoff before it enters the main body of the rain garden. A few methods for accomplishing this include:

- Vegetated filter strip - Directing flow into the garden as sheet flow over a vegetated surface, like a lawn. This spreads the stormwater to limit concentrated flow (and the associated erosive velocities) and to allow filtration by the grass. This can also increase the volume of infiltration at the site.

- Swale – A swale can also increase stormwater infiltration and sediment filtration. See Section 8.0 for more information on designing swales. Stone or rip-rap can be used at the entrance to the rain garden if velocities exiting the swale are too high.

- Forebay – A forebay can be used at the entrance of the garden to pool water, settle sediment, and dissipate energy before flow enters the main body of the rain garden. These features should be used particularly in larger watersheds.

- Gravel verge – This method should frequently be used when space is limited or when stormwater enters as sheet flow from an impervious surface directly adjacent to the garden, such as from a driveway. Figure 5.5 shows a gravel verge and vegetated filter strip combination on the slope of a rain garden. Sheet flow leaving the impervious surface should first contact a strip of washed 57 stone over geotextile fabric and then a grass strip. Each section should be at least 1 foot wide.

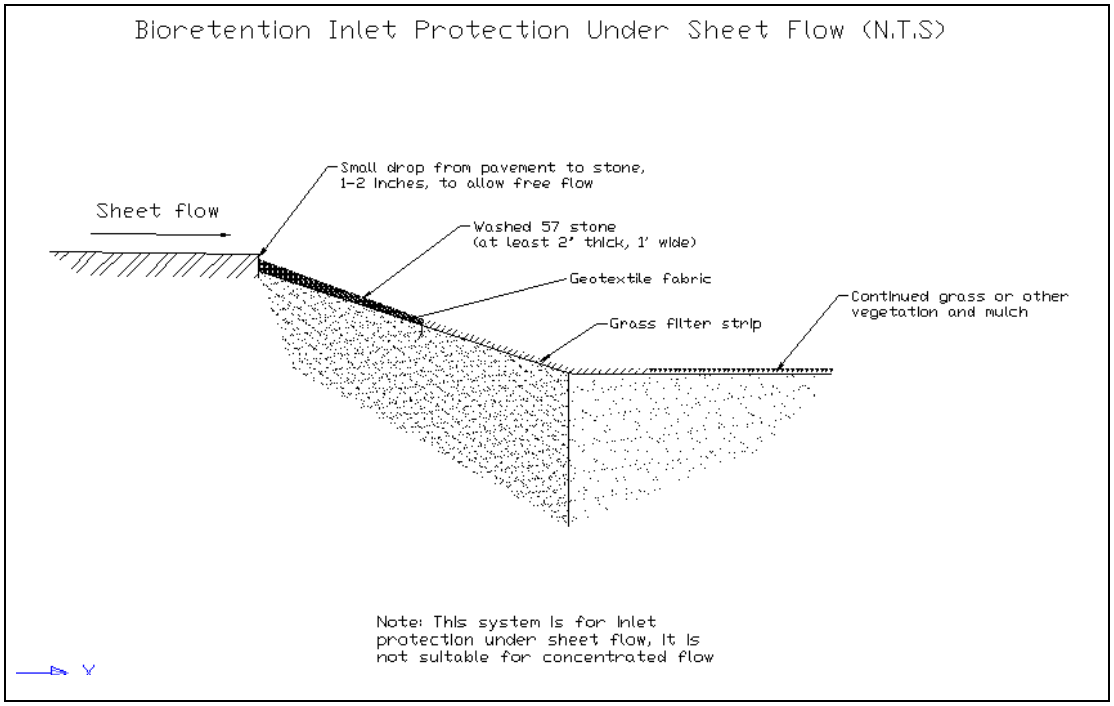

Bioretention Inlet Protection Under Sheet Flow (N.T.S)
Sheet flow
Small drop from pavement to stone, 1-2 inches, to allow free flow
Washed 57 stone (at least 2' thick, 1' wide)
Geotextile fabric
Grass filter strip
Continued grass or other vegetation and mulch
Note: This system is for inlet protection under sheet flow, it is not suitable for concentrated flow

Figure 5.5 A gravel verge and grass filter strip for use in dissipating energy and removing sediment from sheet flow into a bioretention cell

Figure 5.6 A gravel verge precedes a sod filter strip leading into this bioretention area (rain garden).

5.3.7 Outlet design

The outlet structure controls the ponding depth in the rain garden and allows excess flows to exit the garden in a controlled manner without damaging any berms used to form the garden or the drainage infrastructure. The first step in designing an outlet structure is determining the peak flow of the desired design storm for the given watershed, often the 10-year storm. Section 3.4 discusses the use of the Rational Method for calculating peak flow rate. A weir structure is commonly used for bioretention cells, with the weir sized so not to be overtopped during the peak of the 10-year storm. During the peak flow of the 10-year storm, all higher velocity outflow should be in contact with the weir, not contacting soil composing the berm. Section 3.5.2 discusses weir sizing. Appendix B describes the layout and construction of a wooden weir structure. For smaller rain gardens, as will often be the case, a simpler structure than what is described in the appendix may be used. For example, a treated 2x12 with a weir notch cut in it, installed using some of the guidance in Appendix B may be sufficient. All structures should extend at least 6 inches below final grade at the base and 12 inches into the sides of the berm. Soil filled around the structure should be well compacted in 4 to 6-inch lifts. The rain garden should be designed so that no sensitive upstream areas are flooded because of the garden during **any** rain event.

5.4 Rain Garden Maintenance

The first step in maintenance of a rain garden is designing the system to be low maintenance. If sediment can be removed before entering the body of the rain garden (using the inlet protection methods discussed in section 5.3.6) maintenance will be less intensive. Any sediment buildup in the garden or in an inlet protection area should be cleared as necessary to prevent clogging of the garden.

Plant health should be monitored during establishment and during droughts, this can help ensure their survival. It may be necessary to water the rain garden in such times, depending on the garden's condition. It is also necessary to check the outlet structure to make sure it is clear and isn't preventing the garden from draining properly. Fertilizers are not recommended, as sufficient nutrients for the plants are delivered from the watershed.

Mulch will need to be replaced 1 or 2 times per year for aesthetics, to shade the soil, and to help keep weeds out. Weeds will arrive in the garden and must be occasionally removed. Pesticides are not recommended for weed control in rain gardens.

Table 5.1 Maintenance Activities for Backyard Rain Gardens

Activity	Frequency
Remove any sediment that has accumulated in garden or inlet (Check contributing watershed for signs of instability)	Once per year or more frequently as needed
Remove trash from rain garden	As needed
Replace mulch in rain garden	Every 6 months
Remove debris from around overflow weir	As needed
Water garden plants	During drought
Remove weeds, prune garden plants	As needed

6.0 Backyard Wetland Design

6.1 Overview of Practice

A backyard wetland, also referred to as a “pocket wetland” or a “wetland garden,” is built in an area that is perennially moist. The wetland is designed such that it will usually be wet, even several days after a rain event. A properly functioning backyard wetland will be substantially more wet than a rain garden and is usually constructed as an alternative to rain gardens. A typical backyard wetland will be a shallow, excavated bowl ranging from 3 to 12 inches deep. Inside this bowl a variety of vegetation is planted. It is essential that a variety of plants are grown in the wetland to avoid a monoculture and potential mosquito hazard. Wetland vegetation tends to grow densely. Stormwater wetlands are most frequently used to treat large watersheds, such as shopping centers and residential communities; however, in locations with high water tables, pocket wetlands can capture runoff from small watersheds such as an individual property. Figures 6.1 and 6.2 show a wet spot in a yard (an ideal location for a pocket wetland) and types of vegetation found in a backyard wetland, respectively.

Figure 6.1 A perennially wet spot in a yard is a good location for a pocket wetland.

Figure 6.2 This pocket wetland, in Tarboro, NC, features vegetation such as lily pads, pickerelweed, and joe pye weed.

6.2 Selection of this practice over others

Backyard wetlands are used in similar environments as rain gardens. As with rain gardens, backyard wetlands should be located in a low area where stormwater naturally drains. This will ensure that the wetland will operate properly during storm events. The wetland should also be located near the current surface drainage system (the drop inlet or swale that currently drains the watershed). This will allow the designer to direct stormwater that overflows the wetland to the current surface drainage system via a swale or overland flow. By directing the stormwater overflow to the current surface drainage system, no additional drainageways will be required to direct stormwater off the property.

There are a number of other siting concerns for backyard wetlands. To avoid contact between the infiltrated stormwater and any building foundations, the wetland should be located at least 10 feet away from any foundations. The wetland should be at least 25 feet away from any septic system drain fields and 25 feet away from any well heads. Because stormwater wetlands are located in areas that are perennially wet, they tend to be placed down slope of wells and septic tanks and well away from home foundations. Utility lines should be located and marked prior to any soil excavation. For the best plant growth, the stormwater wetland should be located in an area that receives partial to full sun exposure to allow plant growth.

In general, backyard wetlands should be selected over other BMPs when site conditions involve poorly drained soils and/or high water tables. When an initial soil investigation is performed, if the seasonal high water table (Section 3.8) is within 1-foot of the soil surface, the site should be considered for a backyard wetland. Additionally, if the soil investigation shows the soils to be poorly drained (Section 3.7) the site will be more suitable for a backyard wetland than a rain

garden. Another way to verify that a site has poorly drained soils is to identify the spot at a given property where standing water is present for multiple days after a rain event. If the initial simplified soil infiltration test described in Section 3.7.2 results in the test hole draining in between 1.5 and 4 days, a “drought tolerant” wetland should be constructed at the site. More information on drought tolerant wetlands is given in Section 6.3.6.

SWCD staff should evaluate sites with poorly drained soils extremely carefully. The overwhelming majority of CCAP projects will be too small to impact jurisdictional wetlands, if wetland soils are detected on a large project (> 1/4 acre) then the property should be evaluated by a member of the Army Corps of Engineers and/or the North Carolina Division of Water Quality – 401/404 Wetlands Unit.

6.3 Backyard Wetland Design

6.3.1 Determining wetland watershed characteristics

The first step in backyard wetland design is determining the watershed area that drains to the proposed site. The percentage of impervious area in this watershed should also be determined. This impervious area will most likely consist of driveways and rooftops. In order to capture stormwater runoff from driveways and other associated parking areas, the drainage must naturally flow to the proposed location. Rooftops normally are drained via gutters which may or may not drain to the proposed location. In this case, either a 4- to 6-inch plastic flexible pipe or a diversion berm (Section 3.5) can be used to direct this water to the proposed rain garden location. After any modifications are considered (routing rooftop drainage to the proposed area) the total area draining to the proposed location and the percentage of impervious area in the watershed can be calculated

Manual measurements taken with a tape measure can help determine the watershed area, as well as the area draining from driveways, patios, and parking areas. The rooftop area can be measured manually or housing plans can be obtained. If the total rooftop area is known, a judgment must simply be made on how much of the roof drains to a given downspout that will be routed to the backyard wetland location.

6.3.2 Backyard wetland sizing

Backyard wetlands should be sized such that the ponding depth of the captured runoff is no more than 9 inches. In some cases, a property owner may desire a larger wetland; if so, the ponding depth can be as little as 3 to 6 inches. Using the volume of runoff produced in the contributing watershed, and this maximum ponding depth, the surface area of the wetland can easily be calculated. The

shape of the backyard wetlands that are installed as part of the CCAP will vary upon topography, obstructions (e.g., trees and utilities), and landowner desires. The shape will largely be determined by the available space at the stormwater collection point, aesthetic appeal should also be considered. In general, neither the length nor the width should be less than 3 feet.

Once the watershed size and the percentage of impervious area have been calculated, the Simple Method (Section 3.3) can be used to determine the volume of water that will enter the BMP during the first flush event. The wetland surface area will simply be this volume divided by the ponding depth desired for the site. The figures in Appendix D use the simple method to determine the BMP surface area that is required for various watershed scenarios (various sizes and impervious percentages). These figures can be used to size a stormwater wetland for 3, 6, and 9 inch average ponding depths.

6.3.3 Backyard wetland inlet considerations

As stormwater enters the wetland from a pipe or swale, the energy of the stormwater can cause erosion. Placing a check dam in the path of the stormwater just before it enters the wetland will reduce the velocity of the water. This check dam can be constructed of rolled erosion control matting or with 6" – 8" nominal diameter rip-rap. This may not be required in all situations; however, if the slope of the swale or pipe entering the backyard wetland is steep (>6%), erosion is likely to occur. Examples of check dams constructed of erosion control matting and rock are shown below in Figures 6.3 and 6.4.

Figure 6.3 Swale leading to BMP with check dams constructed of rolled erosion control matting

Figure 6.4 Swale with check dam constructed of stone
(Source – USDA – Natural Resource Conservation Service – Illinois)

6.3.4 Backyard wetland outlet considerations

The outlet structure controls the ponding depth in the backyard wetlands and allows excess flows to exit in a controlled manner without damaging any berms used to form the wetland or the drainage infrastructure. The first step in designing an outlet structure is determining the peak flow of the desired design storm for the given watershed, often the 10-year storm. Section 3.4 discusses the use of the Rational Method for calculating peak flow rate. A weir structure is commonly used for wetlands, with the weir sized so not to be overtopped during the peak of the 10-year storm. During the peak flow of the 10-year storm, all higher velocity outflow should be in contact with the weir, not contacting soil composing the berm. Section 3.5.2 discusses weir sizing. Appendix B describes the layout and construction of a wooden weir structure.

For smaller rain gardens, as will often be the case, a simpler structure than what is described in Appendix B may be used. For example, a treated 2x12 with a weir opening, installed using some of the guidance in Appendix B may be sufficient. All structures should extend at least 6 inches below final grade at the base and 12 inches into the sides of the berm. Soil filled around the structure should be well compacted in 4 to 6-inch lifts. The backyard wetland should be designed so that no sensitive upstream areas are flooded because of the wetland during **any** rain event.

6.3.5 Backyard wetland plants

Wetland plants, like any other plant species, have specific environments that they thrive in. Most notably for backyard wetlands, water depth plays an important role in plant selection. For the purposes of the CCAP, these water depths will be divided into three groups: upland plants (not normally in contact with surface water – planted around rim of wetland where roots can access moist soil), shallow water plants (water depth consistently between 0 and 4 inches), and deep water plants (depths consistently greater than 6 inches).

A short list of plants which thrive in each environment is shown in tables 6.1, 6.2 and 6.3. This information was gleaned from "A Citizen's Guide to Protecting Wilmington's Waterways."(Butler, 2005) Additional plant choices are available, especially with regard to perennials. A local cooperative extension horticulture agent should be contacted for additional plant choices. In times of extreme drought, the land owner is encouraged to water the wetland as needed based on the condition of the plants (if they show signs of stress due to lack of rain)
Most backyard wetlands will NOT retain water deep enough for a long enough period to support deep water plants. However, if after the wetland has been constructed the property owner observes 6- to 9-inch deep water reliably in the spring, summer, and fall, the plants listed in table 6.1 should be incorporated into the planting scheme.

Some rules-of-thumb for backyard wetland plant selection include:

(1) Choose native species. Nearly all the species provided in tables 5.3 through 5.5 are native to most of North Carolina

(2) Include evergreen vegetation to provide some color in the backyard wetland during the winter months

(3) Select a few species of plants with showy flowers, which will attract butterflies and dragonflies. This will add aesthetic appeal (butterflies) and an important mosquito predator (dragonflies) to the BMP.

Table 6.1 Sample deep water wetland plants[1]

Common Name	Scientific Name	Comments
American Lotus	*Nelumbo lutea*	Bold plant with foliage and flower stems standing 4' - 6' above water's surface. Large, showy yellow flowers produced throughout summer.
Spadderdock - Cow Lily	*Nuphar luteum*	Heart shaped leaves float on water's surface, 1"-2" wide, globe shaped, yellow flowers are born throughout summer
Fragrant Water-Lily	*Nymphaea odorata*	Rounded, heart shaped leaves float on water's surface. Large, white, sweetly fragrant flowers open throughout summer

[1]*It should be noted that if the water level in the wetland is not consistent and normally drains in between rain events, the deep water plants should not be used.*

Table 6.2 Sample shallow water wetland plants

Common Name	Scientific Name	Comments
Arrow Arum	*Peltandra virginica*	Elegant arrowhead shaped leaves and interesting green flowers on a clump forming plant
Pickerelweed	*Pontederia cordata*	Upright plant producing numerous 3' tall spikes topped with blue flowers all summer. Tough and attractive.
Lizard's Tail	*Saururus cernuus*	Spreading perennial that will grow in shallow standing water and wet soils. Pendant spikes of white flowers in late spring and summer.
Duck Potato	*Sagittaria latifolia*	Tough emergent aquatic with arrowhead shaped leaves and spikes of white flowers produced throughout summer. Reproduces rapidly.
Soft Rush	*Juncus effusus*	Common rush found throughout NC. 2' - 3' tall with dark green spiky foliage. Green flowers are to brown seed pods throughout summer. Near evergreen.
Woolgrass	*Scirpus cyperinus*	Large, 3' - 4' tall and wide clump forming bulrush producing wooly green flower heads in summer that age to an attractive rusty brown as seed mature

Table 6.3 Sample upland wetland plants

Common Name	Scientific Name	Comments
Swamp Milkweed	*Asclepias incarnata*	Pink flowers in early summer. Larval food of monarch butterflies.
Joe Pye Weed	*Eupatorium fistulosum*	Masses of rosy-mauve flowers in late summer-fall attract butterflies
Swamp Sunflower	*Helianthus angustifolius*	Towers of 3" wide golden sunflowers in fall - attracts butterflies
Red Star Hibiscus	*Hibiscus coccineus*	Tough, clump forming, sturdy plant with star shaped red flowers in summer
Rose Mallow	*Hibiscus moscheutos*	Tough, durable plants with huge white, pink or rose flowers in summer
Cardinal Flower	*Lobelia cardinalis*	Tall spikes of crimson red flowers in late summer and fall - attracts hummingbirds and butterflies
Soft Rush	*Juncus effusus*	Common rush found throughout NC. 2' - 3' tall with dark green spiky foliage. Green flowers are to brown seed pods throughout summer.

6.3.6 Drought tolerant wetland

As noted in Sections 6.2 and Table 3.4, the results of the simplified soil infiltration test will sometimes lead to the decision that the soil in question is neither poorly drained nor well drained. Thus, it is not suitable for a standard rain garden or a standard wetland. A modification of these practices is needed for the range of

soils between poorly and well drained. When the test hole at a given location drains in 1.5 to 4 days, and the soils at the site have a significant clay content, the site will likely support a wetland. However, the wetland that is constructed must the drought resistant.

In general, drought resistant wetlands can be designed and constructed in the same way that regular wetlands are designed and constructed. The main difference in these wetlands is the plant selection. The major danger in allowing a backyard wetland to dry is plant mortality. Thus, selecting hardy, drought tolerant plants will result in a well functioning wetland under these drier conditions. Table 6.4 shows a set of suitable plants that can grow in these harsh conditions.

Table 6.4 Plant selection for drought resistant wetland

Common Name	Scientific Name	Plant Type
Soft Rush	Juncus effusus	perennial
Joe Pye Weed	Eupatorium fistulosum	perennial
Rose Mallow	Hibiscus moscheutos	perennial
Ironweed	Vernonia novaboracensis	perennial
Blue Flag Iris	Iris virginica	perennial
Blue Star	Amsonia tabernaemontana	shrub
Buttonbush	Cephalanthus Occidentalis	shrub
Virginia Willow	Itea Virginica	shrub
Possumhaw	Viburnum Nudum	shrub
Winterberry	Ilex Verticillata	shrub
Green Hawthorn	Crataegus Viridus	small tree
Possumhaw	Ilex Decidua	small tree
Sweet Bay	Magnolia Virginiana	small tree
River Birch	Betula Nigra	Tree
Bald Cypres	Taxodium Distichum	Tree

In times of extreme drought, even the drought tolerant plants in the wetland may be impacted by the lack of water. If the plants begin to dry out and show signs of stress consistent with a lack of water (such as wilted foliage), the plants should be watered. The wetland can be irrigated in the same manner as any adjoining lawn, and can obviously tolerate more irrigation than a standard lawn (if resources are available).

6.4 Backyard Wetland Construction

6.4.1 Laying out the wetland

Once the suggested wetland surface area has been determined and a location has been selected, marking paint, string / rope, or flags can be used to lay out the perimeter of the wetland (Figures 6.5a and 6.5b). The wetland dimensions

will vary based on site conditions and landscaping preferences. The layout should be measured multiple times before digging to ensure that the suggested surface area of the wetland is achieved with the dimensions that have been marked.

Figures 6.5a and 6.5b Mark wetland area prior to excavating the area

6.4.2 Digging the wetland

After the wetland area has been laid out, digging can commence. Topsoil should be removed and stored by the side of the wetland (this topsoil will be put back into the wetland later). If the BMP is built on a slope, the remaining soil removed from the wetland area should be placed around the wetland perimeter to create a berm that will retain the stormwater (Figures 6.6 and 6.7). If it is not built on a slope, the entire BMP can be dug into the ground and no berm is required (Figure 6.8). In this case, the soil is not needed for a berm and can be discarded.

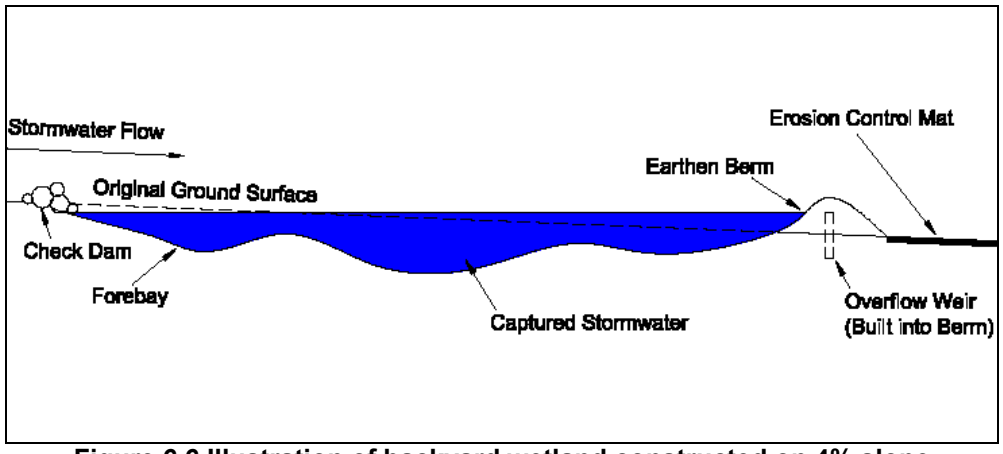


Figure 6.6 Illustration of backyard wetland constructed on 4% slope

Figure 6.7 Berm Construction at downslope edge of BMP

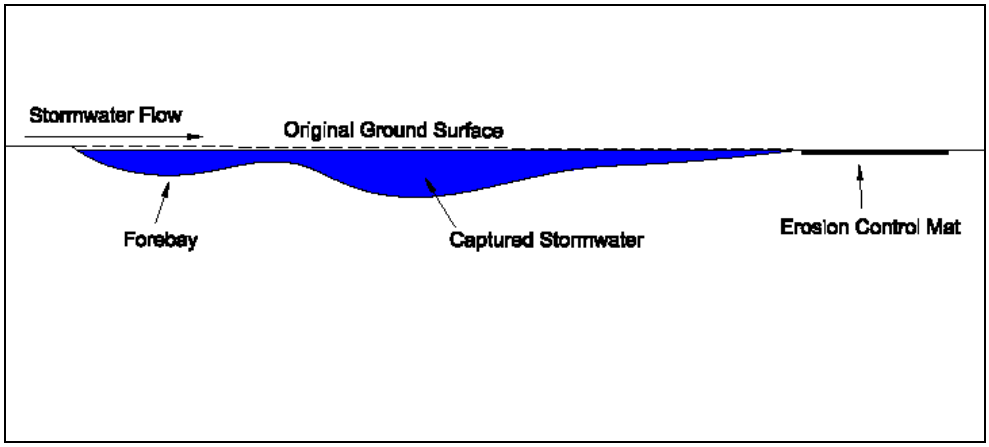


Figure 6.8 Illustration of backyard wetland constructed on 0.5% slope

Since an average depth of 9 inches is desired, some areas in the wetland can be as deep as 1-foot, while other areas will be 3 inches or less. The depth is found by measuring down from the top of the overflow weir (or lowest elevation along the wetland perimeter if no weir is used) to the excavated soil surface. Building variability into the wetland with respect to water depths encourages plant diversity. If the water table is encountered while digging the wetland, this is a good sign that wetland vegetation will survive in this location. The topsoil will be added back to the wetland after it has been dug; thus, the wetland may have to be a little deeper to account for the reapplication of the topsoil. A small, deeper section (forebay) can be included in the wetland design were the stormwater initially enters. This forebay will cause some influent sediment to fall out and will dissipate the energy of the stormwater, reducing erosion inside the BMP. Often, if the watershed is small (<0.5 acres) and stable, a forebay is not needed.

When a backyard wetland is constructed on a slope, the berm height will vary based on the severity of the slope. In general, the berm should not be more than 1 foot higher than the surrounding ground surface. This will minimize the erosive

potential of any stormwater that spills over the back side of the berm. The berm should be stabilized with grass seed and straw after the construction is complete. During the period before the grass has been established, the berm will be susceptible to erosion and should be checked after every rain storm. If the property owner desires, sod strips can be used to stabilize the outlet berm. An outlet should be constructed as described in Section 6.3.4 to provide safe passage of stormwater overflow whenever a berm is necessary.

Whether the BMP is constructed on a flat landscape or one that is sloped, a strip of erosion control fabric (the width of one roll of fabric, which is approximately 6 feet) should be added immediately downslope of the backyard wetland. This is shown in both Figures 6.6 and 6.8. This erosion control fabric will help prevent erosion as the water leaves the wetland.

After the berm and outlet structure have been constructed, the internal cavity, or bowl, of the wetland can be prepared. If the wetland is not sited where the water table will be readily accessed by plant roots (high water table –Section 3.8), the wetland plants will rely on ponded stormwater remaining in the wetland due to poor infiltration. In locations where poor infiltration is relied upon, a hand tamper or other mechanical compactor can be used to compact the underlying soils. This compaction will result in reduced soil infiltration, leading to improved water retention within the wetland.

After the underlying soils have been prepared, the topsoil that was removed should be reapplied on top of the underlying soils at a depth of 2 – 3 inches. This topsoil can be raked into the underlying soils to provide a suitable media for plant growth, this topsoil should not be compacted. Some 10-10-10 slow release fertilizer may also be added to the soils in small quantities to initiate plant growth. After initial fertilization, the wetland should not be fertilized again. In many cases, the wetland soil should also be limed. To verify pH, soil samples can be sent to the NCDA&CS laboratory in Raleigh for testing.

6.4.3 Planting the wetland

Some wetland plants can be purchased at home improvement stores, others will only be available at specialty native plant nurseries. Plant nurseries can also provide valuable insight on plant selection. Planting wetland vegetation is similar to planting any other type of vegetation. A trowel or shovel can be used to create a small hole for planting. Wetland plants should be placed in the location around the wetland in which they are best suited, the zones discussed in Section 6.3.5 are a good guide in planting the various species in the correct environment. The depth of zones is found by measuring from the top of the overflow weir (or lowest elevation along the wetland perimeter if no weir is used) to the underlying soil.

6.5 Backyard Wetland Maintenance

Backyard wetlands must be maintained to ensure their long term functionality. As mentioned earlier, the BMP should initially be checked frequently (every month) for signs of erosion around the containment berm (if one is present), where the stormwater enters the system, and just downslope of the wetland. All three of these locations may be prone to erosion. If erosion is observed, the area can be graded with a rake and shovel and reseeded. Erosion control matting and check dams (described above) can be installed if additional protection is required. Once the vegetation has established and if there have been no signs of erosion, inspection frequency can be decreased to only following storms exceeding 2 inches.

Invasive species can result in reduced plant diversity within the wetland. Cattails are one species that often becomes established in stormwater wetlands. The herbicide; aquatic formulations of glyphosate (example trade name of Rodeo®) can be applied to the cattail stalks, resulting in plant mortality. This should be performed the first time a cattail is identified in the wetland, typically in mid-spring. Care should be taken when using these chemicals. A chemical-resistant glove should be worn whenever handling herbicides. An easy way to apply the chemical is to wear a cloth glove over the chemical resistant glove and to let some of the chemical soak into the cloth glove. The stalks can simply be wiped with the cloth glove. For a detailed description of this method of removing cattails, please see Stormwater Wetland and Wet Pond Maintenance (Hunt and Lord) available in Appendix G.

Additional maintenance activities include such things as cleaning out the sediment that has accumulated in the forebay of the BMP (using a shovel), and picking up any trash that has entered the wetland.

Table 6.5 Maintenance Activities for Backyard Wetlands

Activity	Frequency
Monitor wetland for signs of erosion	Initially every month until stabilization and after any large storm (> 2 inches)
Remove sediment from forebay	As frequently as once per year, if ever.
Remove trash from wetland	As needed
Remove invasive species	As needed, typically mid-spring.
Remove debris from around overflow weir	As needed

7.0 Cistern Design

7.1 Overview of Practice

Cisterns are perhaps the oldest rainwater treatment practices. They are used to capture runoff, primarily from roof tops. Sometimes runoff from pavement is also temporarily held in cisterns. A cistern is simply a tank that stores runoff. These tanks range in size from thousands of gallons to as small as 50 gallons. The small version of a cistern is known as a rain barrel. Cisterns can be employed above or below ground, with the former type of cistern typically being cheaper to purchase and install. Above ground cisterns will be the focus of this document. These systems vary in size, color, and shape. Figures 7.1, 7.2, and 7.3 show examples of cisterns installed in various locations in North Carolina.

Figure 7.1 3,000-gallon cistern installation in Greenville, N.C.

Figure 7.2 5,600-gallon cistern in Kinston, N.C.

Figure 7.3 300-gallon cistern in Greenville, N.C.

The cistern is part of a larger system, consisting of gutter diversions, outlet lines and often a pump (Figure 7.4). This system is referred to as a rainwater harvesting system. Rainwater captured in cisterns is used, or harvested, for uses such as irrigation, toilet flushing, vehicle washing, and clothes washing. Irrigation and car washing are expected to be the primary use for stormwater collected in backyard cisterns. These uses are non-potable (non-drinkable) only. It is important to alert users that this water is not for drinking such as was done in Figure 7.3.

Figure 7.3 Warning signs on a cistern to prevent human intake of the stormwater

The demand for cistern water and the size of the cistern relative to the contributing watershed (rooftop) tends to govern how much runoff reduction the water harvesting system provides. Because rain barrels tend to be very undersized, they do not provide as much runoff reduction when compared to larger multi-hundred or multi-thousand gallon cisterns.

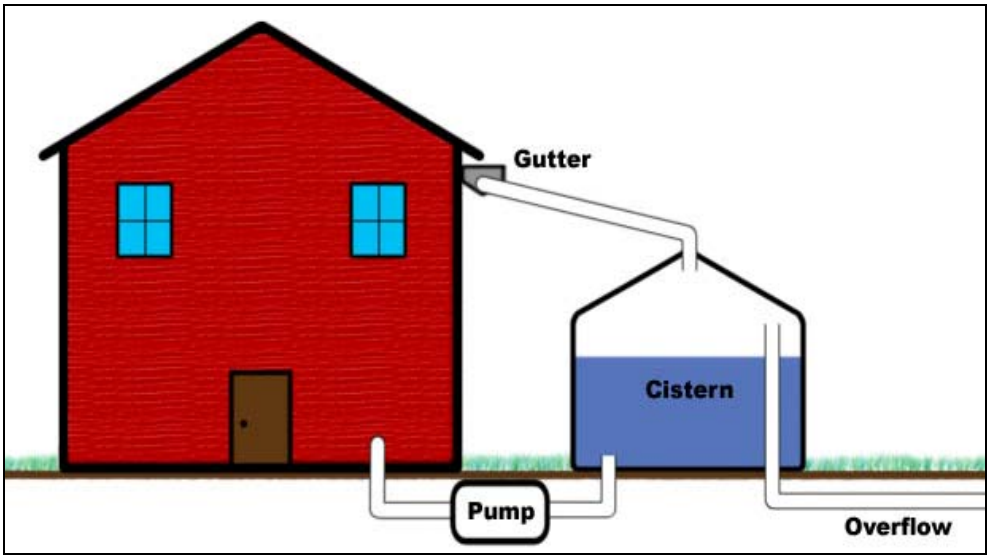


Figure 7.4 Schematic of cistern system

7.2 Selection of this practice over others

The primary advantage of installing a stormwater cistern is that the stormwater can be captured and used for some other objective. In other BMPs, stormwater is lost to the atmosphere, is used by plants, or drains into the soil. A property owner should be able to describe the intended use of the stormwater to SWCD staff. This is important because the cistern is only an effective BMP if it has storage space. Storage space is created by using the cistern water between rain events. Cisterns can be installed, in many cases, without excessive digging, and soil type and water table depth have little impact on above-ground cistern installation.

The disadvantage of using cisterns is that they will only treat runoff from rooftops in a backyard stormwater BMP setting. Thus, rain gutters are necessary on the rooftops being treated. SWCD will not provide any cost-share for gutter installation. Any runoff produced by parking lots or other impervious surfaces are typically not captured by the cistern.

7.3 Cistern Design

7.3.1 Determining Cistern Watershed Characteristics

Determining the characteristics of the watershed draining to the cistern is relatively easy. Since the cistern will be receiving drainage from a rooftop, the rooftop area draining to the gutters feeding the cistern should be determined. Design plans, internet tax maps, and site measurements can be used to determine the drainage area.

7.3.2 Cistern sizing

The first step in cistern sizing is to determine the volume of stormwater that is to be captured. These systems capture runoff from areas that are, in most cases, 100% impervious. The simple method described in equations 3-1 and 3-2 can be applied to these rooftop watersheds to estimate the volume of runoff that can be expected for a given storm event. It is unreasonable to capture the entire first flush (1 or 1.5 inches, depending on location) due to the size of cistern that would be required to do so. Thus, a reasonable water quality and volume reduction can be achieved by capturing the first 0.5 inches of rainfall (0.75 inches in CAMA counties).

An appropriately sized cistern can be selected based on the capture volume that was calculated. Cisterns come in standard sizes and shapes, so the cistern may be slightly over or under sized based on the desired volume and the available cistern sizes. Table 7-1 shows the estimated runoff associated with various rooftop areas and a suggested cistern size for each rooftop. The cistern manufacturer should be contacted to determine what size cisterns are available. Plastic cisterns are more desirable for the purpose of the CCAP, and a range of colors are available to suit aesthetic needs.

Table 7.1 Estimated Runoff Volumes and Cistern Suggestions for Various Rooftop Areas

Rooftop Area (ft^2)	0.5-inch			0.75-inch		
	Runoff Volume (cf)	Runoff Volume (gal)	Suggested Cistern Size (gal)	Runoff Volume (cf)	Runoff Volume (gal)	Suggested Cistern Size (gal)
250	10	74	65 (rain barrel)	15	111	133 (rain barrel)
500	20	148	133 (rain barrel)	30	222	210
750	30	222	210	45	333	300
1000	40	296	300	59	444	550
2000	79	592	550	119	888	1000
3000	119	888	1000	178	1332	1500
5000	198	1480	1500	297	2221	2500

Because cistern sizing is based upon water supply and demand, the chart provided above will often undersize, but occasionally oversize, the cistern. The preferred way to determine the size of a cistern is to run a simple water budget model such as those available on the following website: http://www.bae.ncsu.edu/topic/waterharvesting.

This model simulates 30 years of actual rainfall data from several cities in North Carolina and couples this “supply” of water with user defined demands – such as the number of gallons of water used per week to irrigate and wash vehicles. Before a cistern is installed, it is highly recommended that the eventual operator

of the cistern know how much water he/she is using on a daily basis. This information can be obtained using a simple hose-attached water meter, available for purchase at most garden centers. The model will show the optimal size for a cistern based upon runoff reduction, nutrient removal, and payback period (cost). More information on this model is provided in Appendix H.

7.3.3 Additional Cistern Components

A few additional components may be desirable to ensure proper cistern function and to increase the usability of the collected rainwater. Most notably, a filter should be used to remove leaves and large debris that have made their way down the gutter with the stormwater. This filter can be placed just below the gutter downspout where the stormwater enters the cistern (Figure 7.5)

Figure 7.5 Debris filter just below gutter downspout

An overflow assembly is part of the cistern as well. This assembly generally consists of a system of pipes that attach to the overflow orifice that is built into the cistern. If the cistern does not have enough storage space to capture an entire rain event, this system of pipes allows any overflow stormwater to leave the cistern and discharge onto the ground below without cascading down the side of the cistern (Figure 7.6 and 7.7).

Figures 7.6 and 7.7 Overflow assembly on cistern

Additional equipment may be needed to access the cistern water, such as spigots and other pipes. The cistern vendor should be contacted to determine exactly what outlet configuration will be required to access the cistern water for a given water usage. In some cases, a pump will be required to send the stormwater to the point of usage. Vendors can give some guidance on pump sizing. A North Carolina Cooperative Extension publication has been produced that will also aid in pump selection. This document has been attached as Appendix I.

7.3.4 Outlet structure

Cisterns have an internal overflow device that is used when they do not have enough storage space to capture a given rain event (Figure 7.6 and 7.7). The quantity of stormwater that overflows or bypasses the cistern will vary depending on event size. Thus, some effort should be made to route the overflow stormwater to a nearby drainageway. This may be done via a swale or plastic drainage line. Failure to do so may result in the formation of an erosion channel where the stormwater leaves the cistern.

7.4 Cistern Construction

7.4.1 Preparing the soil base

Cisterns are extremely heavy when full of water. A stable, level, soil base is needed to ensure the stability of the cistern. If the site is not level, the cistern could tip and fall. The area to be occupied by the cistern should be cleared of any vegetation or debris that could make the cistern unstable over time (Figure 7.8a). Cisterns that are 1500 gallons or greater in size may require some additional stability underneath. A level depression (12 – 18 inches) can be excavated in the shape of the cistern before a gravel base (~ 4 – 5 inches) is laid down for systems 1500 to 3000 gallons (Figure 7.8b). The area of excavation should be a couple feet larger than the footprint of the cistern so the cistern can be shifted into place to receive the stormwater flow (placed underneath the gutter downspout). Larger cisterns (such as those made of metal, exceeding 5000 gallons of storage) should be placed above a 4 to 6 inch concrete pad (Figure 7.9), a hole similar to that described above for the gravel base can be excavated, and the cement can be poured in to the proper thickness.

Figures 7.8a Cistern site preparation and b. Preparing the gravel support base.

Figure 7.9.a Concrete pad constructed to support (b) a 5000 gallon metal cistern.

7.4.2 Preparing the gutter downspout

As mentioned previously, gutters should already be installed when a cistern is to be implemented. The cistern can temporarily be sat in the excavated area near its final location. Since the downspout should still be in place, it will not be possible to place the cistern exactly in its final location. The height of the top of the debris filter should be marked on the gutter downspout. Since the screen that actually filters the water lies just below the top of the debris filter (See Figure 7.5), the location of that screen should be marked on the downspout as well. The cistern can then be moved back out of the way.

The gutter downspout should be cut approximately 2 inches up from the location of the screen that will filter the stormwater. This will keep the downspout within the confines of the debris filter walls, but allow the cistern to be positioned properly. The downspout can be cut with a hack saw, or by another method that will produce a smooth, straight edge.

7.4.3 Preparing the gutter downspout

As mentioned previously, gutters should be present where a cistern is to be installed. The cistern can temporarily be placed in the excavated area near its final location. Since the gutter downspout should still be in place, it will not be

possible to fix the cistern in its final location (since the cistern will sit under the gutter once the gutter has been cut). The height of the top of the debris filter should be marked on the gutter downspout. Since the screen that actually filters the water lies just below the top of the debris filter (See Figures 7.10 and 7.11), the location of that screen should be marked on the downspout as well. The cistern can then be moved back out of the way.

Figure 7.10 Gutter empties into cistern screen

Figure 7.11 Cistern screen close-up

The gutter downspout should be cut approximately 2 inches above the location of the filter screen. This will keep the downspout within the confines of the debris filter sides, but allow the cistern to be positioned properly. The downspout can be cut with a hack saw, or by another method that will produce a relatively smooth, straight edge.

7.4.4 Setting the cistern into place

Once the site has been properly prepared, the cistern can be set into place. The cistern should be situated such that the gutter downspout can feed into the debris screen that is attached to the top of the cistern. If the gutter downspout and the base have been prepared properly, this should be easy to do. By preparing a support base surface area slightly larger than the cistern, the cistern can be shifted into the proper place (Figure 7.12a and 7.12b).

Figure 7.12a Proper cistern placement (b) prepare an area slightly larger than the cistern

7.4.5 Final cistern construction considerations

The last step in the construction process is to attach the overflow apparatus and any spigots or other distribution apparatus. Teflon tape should be used on any joints where a water tight seal is desired. Pumps should be installed per manufacturer's recommendation.

7.5 Cistern Maintenance

Maintenance is crucial to cistern performance. Most notably, the gutters and the debris screen should be checked for leaves and other debris. Since these two components are essential in routing stormwater to the cistern, they should be checked frequently, particularly when a tree canopy is near a roof top. Any hose or pipe connections associated with the cistern should be checked for leaks. The cistern should also be checked for stability. If the cistern is consistently low on stormwater, it may become light and require some sort of anchoring system to keep it in pace. If a windy storm event is possible, such as before a tropical storm, the owner of the cistern may want to fill it part way with potable water to prevent the wind from tipping the cistern. A list of maintenance activities and their associated frequency is shown in Table 7.2.

Table 7.2 Cistern Maintenance Activities

Activity	Frequency
Clean gutters of debris that have accumulated, check for leaks	Bi-annual
Clean debris screen to allow unobstructed stormwater flow into the cistern	Monthly
Winter-proof system	Fall
Check cistern for stability, anchor system if necessary	Bi-annual (Spring / Fall)
Check accuracy of water level indicator if present	Annual
Check pipe and valve connection for leaks	Annual
Make sure cistern manhole is accessible, operational, and secure	Annual
Fill tank ½ full with water (if tank is less than ½ full)	Before any major wind related storms (such as tropical storms or hurricanes)

8.0 Vegetated Swales

8.1 Overview of Practice

Swales often serve to convey water around and away from businesses and residences. They are vegetated, open channels, most often lined with grass. From a water quality perspective, they are preferable to pipes because they allow more soil/water contact and more opportunity for infiltration. Filtration of sediment and debris can also occur within swales, especially if the grass is kept relatively long. When swales are designed to be flat and wide, stormwater velocity is decreased, leading to increased soil/water contact and thus promoting infiltration and filtration. Figures 8.1a and 8.1b show a grassed swale.

Figures 8.1a and 8.1b show two swales in the Raleigh-Durham area. Both have turf reinforcement mats. The former in Durham (b) is mowed while the latter in Raleigh (a) contains a taller grass stand.

8.2 Determining Site Constraints

The first step in designing a vegetated swale is to determine the constraints of the site.

Slope
The swale must lead from an upland area where it ties into an existing grade to a lower area where it again ties into an existing grade. Often, swales will lead from a point in the watershed to a BMP or from a BMP to the existing drainage infrastructure. This information can be used to determine the allowable slope of the swale. The swale should have a relatively constant slope between it's inception and destination, the slope should gradually change if necessary.

Slope (S) = elevation change from start to end (ft) ÷ length of swale (ft)

Top Width
The maximum width of the swale may be dictated by site constraints. Determine the maximum width before beginning calculations.

Side Slopes
It may be desirable at some sites to leave the side slopes of a swale mild enough that they can be mowed with a riding lawn mower. If this is the case, a slope of 4:1 (H:V) or flatter is recommended, no steeper than 3:1 is recommended in most cases, and never more than 2:1 unless the designer has extensive experience with swales. Triangular swales can be used on small watersheds less than 2 acres. They can be designed as trapezoidal swales with very small bottom widths.

Shape
Both trapezoidal and triangular cross-sections will be commonly used for water quality swales. The depth of flow within these channels will be shallow during

small storms, allowing increased soil and grass contact with the stormwater, and thus increased infiltration and filtration. Triangular shaped swales are more appropriate for small drainage areas.

Peak Flow
Swales should be designed to convey the peak flow of the 10-year storm without overtopping, as calculated in section 3.4 using the Rational Method. During extreme events (e.g. 25 or 100-year storms) portions of the swale may be breached and should be repaired by the property owner as necessary.

8.3 Depth and Velocity Calculations

Swales should be able to carry their design flow without overtopping or eroding. If the velocity is too high for grass cover in a given swale design and the slope and cross-section cannot be adjusted, the swale can be reinforced with rip-rap or turf reinforcement matting (which can withstand a higher velocity). There are several approaches to designing a swale. A given site may have constraints which dictate the channel slope and cross-section, in which case the designer must simply ensure that the channel lining will be strong enough to handle the velocities produced. Conversely, there may be flexibility with respect to the channel cross-section and the designer may choose to size it such that a simple grass lining will be sufficient to prevent erosion. Figure 8.2 is a diagram of a swale with a trapezoidal cross-section and illustrates some of the parameters discussed in this section. The equations used in trapezoidal channel design are as follows:

Equation 8-1 The Continuity Equation

$$Q = VA$$

Where:
Q = flow rate (cfs)
V = average velocity of the cross-section (ft/s)
A = cross-sectional area of the flow (ft^2)

And:
$A = bd + xd^2$ (refer to figure 8.2)

Equation 8-2 The Manning Equation - can be used to calculate the velocity of the stormwater in a given channel

$$V = 1.49 * (1/n) * R^{2/3} * S^{1/2}$$

Where:

V = velocity (ft/s)
n = Manning roughness (Table 8.1)
R = hydraulic radius (ft)
S = channel bed slope (ft/ft)

The hydraulic radius (R) is equal to the cross-sectional area of flow (A) divided by the wetted perimeter (Wp) (see Figure 8.2), or for trapezoidal channels:

$$R = (bd + xd^2) / (b + 2dx)$$

*all dimensions in ft

For convenience, the top width of the trapezoidal channel can be calculated as:

Swale Top Width = b + 2Dx
*all dimensions in ft

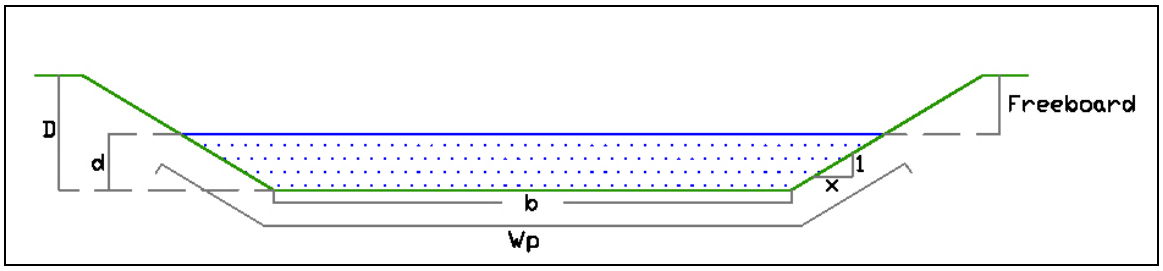


Figure 8.2 Trapezoidal swale cross-section

The correct cross-section must be determined by trial and error. A computer spreadsheet or other software (e.g., TR-55) would be helpful in this process and has been provided to SWCD personnel in the past. Once a channel geometry is assumed, then the Continuity Equation (Equation 8-1) and Manning Equation (Equation 8-2) are used to determine the average velocity of flow for the design storm. A nomograph has been provided in Appendix J that can be used to solve the Manning Equation. Using the maximum permissible velocity method, it can be determined whether the channel will erode. Table 8.2 shows maximum permissible velocities for a variety of channel linings. Manufactured products should have maximum permissible velocity specifications available. If the channel velocity exceeds the maximum permissible velocity for a given surface lining, erosion will occur. It is good practice to design conservatively. Multiply the calculated velocity by a safety factor of 1.3 when comparing with the maximum

permissible velocities in Table 8.2. Assume that grass will not be mowed regularly when selecting a Manning n. Leave at least 0.3 ft of freeboard at the top of the swale during the 10-yr storm. The channel can be reinforced if velocities cannot be lowered sufficiently by enlarging the swale.

Table 8.1 Manning's n values for various channels

Type of Channel Lining	Design n
Riprap	0.035
Earth, straight, uniform, short grass and weeds	0.027
Earth, winding, sluggish, grass and weeds	0.033
Earth, winding, sluggish, dense weeds or aquatic plants	0.04

Figure 8.3 Turf reinforcement mats used along a swale at Umstead State Park.

Table 8.2 Maximum permissible velocities for various channel linings

Type of Channel Lining	Maximum Permissible Velocity (ft/s)
Grass	4
Graded Rock, D50 = 3 in.	6.5
Graded Rock, D50 = 6 in.	9.0
Turf reinforcement mat products	9.5 - 25

8.4 Simplified Triangular Swale Design

8.4.1 Adjusting Manning's equation for simplified triangular swale design

In many cases, a given watershed will be small enough to justify the use of a triangular swale. Some assumptions and generalizations can be made when designing triangular swales, these assumptions will simplify the design process. When the triangular swale cross section is split in half, two right angles are formed (figure 8.4).

Figure 8.4 Triangular swale cross section – broken into two right angles

Breaking the swale into two right angles allows some simplification of the triangular swale design method. By the Pythagorean Theorem (Figure 8.4), we can determine the length of the unknown side "x." In triangular swales with 3 to 1, 4 to 1, or gentler, sideslopes, the length of "x" is found to be approximately the same as the length "y." The "y" value is equal to half of the swale width, thus, the unknown distance "x" is also approximately equal to half the swale width. Because the wetted perimeter (section 8.3) of a triangular swale is calculated as the sum of the two "x" distances seen in the figure above, the wetted perimeter is approximately equal to the swale width.

When constructing a swale with known sideslopes, the width of the swale can be defined in terms of the depth, since they have a consistent relationship with one another. For example, 3 to 1 sideslopes on a swale indicates that for every 1 foot of depth, each sideslope will be 3 feet wide, for a total swale width of 6 feet. In general terms:

$$\text{Swale width} = \text{swale depth} \times 6$$

Also, we can define the area of the swale as:

$$\text{Swale area} = ((\text{swale depth})^2) \times 3$$

With these geometrical assumptions, the equations used to size swales (section 8.3) can be simplified as the area and wetted perimeter can both be written in terms of depth in the hydraulic radius calculation (section 8.3). Thus, our final equations are as follows:

Equation 8-3 Manning's Equation for triangular swales (sideslope = 3 to 1)

$$Qp = (1.49 \div n) \times 1.04 \times D^{2.67} \times S^{(1/2)}$$

Or

$$D = [Qp \times n \div (1.55 \times S^{(1/2)})]^{0.375}$$

Where: Qp = Peak Flow (ft^3/s - section 8.2)
n = Manning's n value (Table 8.2)
D = Swale depth (ft)
S = swale slope (ft/ft)

Equation 8-4 Manning's Equation for triangular swales (sideslope = 4 to 1)

$$Qp = (1.49 \div n) \times 1.26 \times D^{2.67} \times S^{(1/2)}$$

Or

$$D = [Qp \times n \div (1.88 \times S^{(1/2)})]^{0.375}$$

Equation 8-5 Manning's Equation for triangular swales (sideslope = 5 to 1)

$$Qp = (1.49 \div n) \times 1.46 \times D^{2.67} \times S^{(1/2)}$$

Or

$$D = [Qp \times n \div (2.18 \times S^{(1/2)})]^{0.375}$$

8.4.2 Simplified triangular swale design process

With the simplifications made to the Manning's equation for triangular swales, the design process for these practices becomes fairly straightforward. In a basic design scenario, the slope (S) of the swale will likely be set (Section 8.2). Likewise, the peak flow (Qp) from the supplying watershed will be calculated using the rational method. Therefore, the depth of swale (D) and Manning's n will be the only unknowns once a given swale geometry is chosen. If space is available, sideslopes of 4 to 1 or 5 to 1 can be used (most often 4 to 1). This will allow easy access to the swale for mowing equipment. If limited space is available, 3 to 1 sideslopes may be used.

The design process may require a few iterations to achieve an acceptable design. In general, the steps of the design process are as follows:

1. Calculate peak flow for the 10 year storm from the watershed
2. Determine slope from swale beginning to end
3. Select swale geometry (typically 4 to 1 or 3 to 1 sideslopes)
4. Assume n value from Table 8.1 – use n value for grass, make selection based on vegetation and straightness of swale
5. Use equation to determine D (depth of swale – if completely full of stormwater during 10 year storm) – use equations 8-3, 8-4, or 8-5

6. Use D to calculate swale area as define in Section 8.4.1 (also calculate channel width as defined in Section 8.4.1 – make sure space is available – if not, steeper sideslopes may be used)
7. Use area calculated in step 6 and Qp to determine the velocity of the stormwater in the swale during the 10 year storm (use equation 8-1, the continuity equation)
8. Check velocity against table 8.2 to determine if grass alone can withstand the velocity produced in the channel – if so, the design is complete
9. If grass can not withstand the velocity produced in the channel, turf reinforcement matting can be used. If turf reinforcement matting is not desired, rock can be used; however, the design process must be repeated using a different Manning's n value. Always perform a check to determine if the velocity produced in the channel can be passed by the channel lining without eroding.
10. If a safe velocity can not be achieved with a given swale design, the slope of the system can be adjusted by changing the course of the swale or a trapezoidal channel can be used.

8.5 Construction Guidance

Swales can be constructed using a variety of heavy equipment. The equipment used will depend on what is already on site, if anything, and the size of the swale. A small excavator would work well on smaller jobs and may be on site for construction of other BMPs.

If turf reinforcement matting is used, it should be installed according to the manufactures recommendations. Use plenty of staples to stabilize the mat and maintain good contact between the mat and the ground surface in all locations. It is helpful to use short lengths of matting on curves, to avoid bunching. Seed and lime should be applied under the matting, or as suggested by the manufacturer. Native grass will perform the best; however, the grass should only be applied at the proper time of year (proper time varies depending on grass type). The property owner may desire that the grass planted match what is already in their yard. County extension offices can help with grass selection and planting. Temporary seed can be used if construction must take place during a time of year when the onsite grass will not germinate. Annual Rye grass can be used in cool seasons or Millet in warm seasons, for example. If temporary seed is used, the swale must be re-seeded with perennial grass at the proper time of year.

For grass covered swales, the surface should be protected using a suitable erosion control product while seed is being established (to avoid erosion). Sod may also be used in many cases.

8.6 Maintenance

Swale maintenance should consist mostly of mowing. Adjusting the mower to keep the grass long is preferable for filtration. If erosion occurs, the swale may be re-shaped and stabilized. If substantial sediment deposition occurs, it must be removed to allow unobstructed flow in the channel.

Table 8.3 Maintenance Activities for Swales

Activity	Frequency
Mow grassed channel (keep relatively long)	As needed
Check swale for signs of erosion	As frequently as once per month
Remove trash from swale	As needed
Remove deposited sediment which could obstruct flow	As needed
Reseed	If needed – late spring / late summer depending on grass type
Repair Turf Reinforcement Matting	As needed. (rarely a problem if mower does not “catch” the mat)

9.0 Impervious Removal

9.1 Overview of Practice

As discussed in section 2.2, urbanization (characterized by increases in impervious area) can cause a substantial increase in stormwater runoff. One basic stormwater management practice is to reduce the amount of impervious area in a given urbanized area. If an area has already been urbanized, this can be accomplished by removing impervious areas that are no longer needed. Patios, walkways, parking areas, and driveways can all be removed and converted to pervious areas. Gardens, lawn, and permeable pavements all can be used in place of the impervious area.

For permeable pavement costs to be offset by CCAP, it must be accompanied by impervious surface removal.

9.2 Selection of this practice over others

Impervious surface removal should only take place when there is a patio, walkway, parking area, or driveway that is no longer being used, or is going to be converted to a permeable surface. Impervious areas that drain directly into the stormwater sewer system should be targeted. Impervious areas that are directly connected (connected imperviousness – Section 3.2) to the larger stormwater drainage system (via a swale or pipe) have the greatest impact on stormwater runoff. Impervious areas that drain onto pervious areas (forested areas, lawns, etc.) before collecting in the storm drainage network present less of an impact, as runoff from these impermeable surfaces has an opportunity to infiltrate into the nearby pervious area. Impervious surface removal can provide a water quality benefit when there is limited space to construct a rain garden, pocket wetland, or other BMP in the path of the stormwater at it routes to the stormwater sewer system.

Impervious removal should be performed in combination with the creation of pervious areas such as lawn, gardens, or permeable pavement. Permeable pavement conversion can only be performed in the Sandhills and Coastal Plain as part of the CCAP.

9.3 Carrying Out Impervious Removal

While removing impervious area is a simple way to limit stormwater runoff, removing asphalt, concrete, or brick can be challenging. Breaking the impervious area into small pieces and removing these pieces should be performed by a contractor to avoid injury. The impervious area, once broken up, will consist of very heavy, sharp-edged debris. A large truck will be required to transport the debris from the location to a disposal site after heavy equipment, such as a backhoe, breaks the pavement apart and carries it to the truck.

10.0 Permeable Pavement

10.1 Overview of Practice

Traditionally paved surfaces are impermeable, converting nearly all rainfall to runoff. These pavements were designed to be strong, that is, able to withstand heavy traffic. Permeable pavement allows water to pass through it, reducing runoff (Figure 10.1). These pavements are best used in low traffic situations similar to those found in patios, parking pads, and driveways, making them a good “backyard” BMP. Permeable pavements may be constructed of permeable asphalt, pervious concrete, permeable interlocking concrete pavers, concrete grid pavers and grassy pavers (Close up views of many of these surfaces are found as Figure 10.2). They are typically underlain by a gravel support layer ranging in thickness from 4 to 12 inches. Permeable pavements work best when

sited on sandy soils, such as those found on Barrier Islands, the Coastal Plain, and the Sandhills. Permeable pavement should not be placed near active construction zones, as they are prone to clog. An example of a patio constructed of permeable pavement is shown in Figure 10.2, and a residential driveway application is shown in Figure 10.3.

Figure 10.1 Illustration of permeable pavement function – garden hose dispensing onto permeable concrete

Figure 10.2 Four types of permeable pavements (starting top left corner and moving clockwise): permeable concrete, permeable interlocking concrete pavement, grass pavers, and concrete grid pavers.

Figure 10.2 Permeable pavement patio outside a café in Swansboro, NC.

Figure 10.3 Permeable pavement driveway

10.2 Selection of this practice over others

In parts of North Carolina, NC DENR awards a runoff reduction credit if permeable pavement is used in place of traditionally impermeable pavement. This blanket credit for permeable pavement as a stormwater BMP is only available in the Sandhills and Coastal Plain/ Barrier Islands; thus, these backyard practices should only be installed in these two locations. The reason for this geographic limitation is that the stormwater infiltration associated with permeable pavements is limited by the soils in which they are installed. Sandhill and Coastal Plain soils are often sandy and well draining.

It is imperative that in situ soils are analyzed in depth before permeable pavements are installed. A three foot hole should be dug in multiple locations in the proximity of the proposed permeable pavement site. The soils should be well drained (See Section 3.7), with no signs of wetland characteristics within the soil section (the entire 3 feet). (See Section 3.8) Additionally, the infiltration rate at

the site should exceed 2 in/hr throughout the top 3 feet of soil. Infiltration rates at the top of the soil column (within the top 6 inches) can actually be quite low and the pavement will still function well. This is because the pavement is expected to drain from the bottom, which is at least 6 inches from the pavement surface (and usually several inches deeper). This is an important consideration, because often where impermeable surfaces were once located the soil immediately beneath them has been compacted and has become relatively impermeable. In short, the bottom of the permeable pavement is below the compacted area created by the existing pavement (which is to be removed).

The site where the BMP is to be installed must currently consist of impervious area that will be removed and replaced with the permeable pavement. The area must have a very slight slope (less than 0.5%) to allow maximum stormwater storage. This practice should only be used for backyard patios, sidewalks, and residential parking pads. The sites that are selected for permeable pavement installation should not experience heavy vehicular traffic, such as garbage trucks. The traffic load should be consistent with normal residential use. Any parking lot associated with a business or larger than 2 stalls should be designed by an engineer to ensure structural stability.

Permeable pavement should not be used to treat runoff from any adjoining areas larger than the square footage of the permeable pavement itself. It is imperative that these pavements are surrounded by a stable area. No disturbed soil should be present in an area draining to the permeable pavement. Permeable pavement is used primarily to infiltrate the rain that falls onto it.

Typically, if grassed and rooftop areas are to be treated at a given residence, a BMP other than permeable pavement may be more desirable. The collected rainwater will infiltrate into the soil below, thus if water capture and reuse is desirable, permeable pavement is not a good BMP choice. These systems are meant for low traffic areas, and can not handle loads heavier than standard passenger vehicles.

10.3 Permeable Pavement Design

10.3.1 Initial Soil Analysis Field Test

The infiltration rate at the site should be 2 in/hr throughout the top 3 feet of soil. To test this, three holes will be required, each at least 4 feet away from the other (again, this should be done in multiple locations around the proposed site). Each of the three holes will have a different depth, 1-foot, 2-foot, and 3-foot. Each hole should be filled with water. The 1-foot hole should be empty in 6 hours, the 2-foot hole should be empty in 12 hours, and the 3-foot hole should empty in 18 hours. This test is performed to ensure no impermeable layer is present in the top 3 feet of soil.

In general, the soil classification should be no finer than a Loamy Very Fine Sand as defined by the United States Department of Agriculture – Natural Resources Conservation Service. More detail on permeable pavement is available in section 3.10 of the North Carolina Stormwater BMP Manual (2005). If these infiltration criteria are met, the soils at the site meet the screening criteria for permeable pavement installation; however, detailed soil analysis should be performed to ensure that the site is suitable. It is recommended that a soil scientist or a professional competent in evaluating soils be consulted to determine a given soil's permeability if it is questionable.

10.3.2 Soil Analysis Lab Test

If the initial field soil test described in section 10.3.1 indicates that the soils may be suitable for further analysis, soil samples should be taken from the area where the BMP is to be implemented. These samples should be taken to a laboratory for analysis to ensure that they will be structurally sufficient to support the permeable pavement, and will be suitable for infiltrating the captured stormwater. One sample should be taken for every 200 square feet of area to be constructed. Since the area that is to be used for the BMP should be taken up by impervious area prior to the permeable pavement installation, samples may be taken along the periphery of the current impermeable area.

At each sampling location, a hole should be dug to a depth of 3 feet. The topsoil can be discarded (top 6 inches); however, all other soil excavated from the hole should be placed in a bucket and mixed until all soil lenses are combined homogeneously. A sample should be taken from this bucket and placed into a vessel that is approved by the laboratory that will be analyzing the sample (The laboratory selection should be approved by SWCD staff). Again, this procedure should be repeated at each sampling location.

The laboratory should perform a sieve analysis to determine what percentage of the soil sample consists of fines (clay and silt particles – not prone to high infiltration or structural stability). If the percentage of fines is less than 8% (or the amount passing the 270 sieve, which means the sample consists primarily of sand and loamy soils) the soils are suitable as a base for the permeable pavement.

10.3.3 Concrete Edging

Concrete edging should be used around the perimeter of the paved area whenever permeable interlocking concrete pavers are installed (see Figure 10.4). The edging should be approximately 18 inches deep and have a width of 6 inches. This edging will reduce the possibility of the pavement blocks on the edge of the paved area sloughing over. Permeable concrete and concrete grid pavers will not require this edging provided that the very edge of the paved area is not exposed to vehicular traffic.

Figure 10.4 Pavers abutting a concrete edge.

10.3.4 Gravel Base

The gravel base that is laid over the existing soils is used to (1) store captured stormwater and (2) provide structural stability (Figure 10.5). The depth of and type of stone in the gravel base will vary depending on whether permeable concrete or permeable pavers are installed. If the soil criteria described in sections 10.3.1 and 10.3.2 is met, the total gravel base should be approximately 6 inches deep. Any stone used as a gravel base should be washed, effectively reducing the amount of fines in the gravel. If possible, the stone should be double washed. These fines, if not removed, will migrate to the soil sub base and clog the soil pores. This clogging would result in reduced infiltration and, thus, reduced permeable pavement performance.

Figure 10.5 Gravel layers under permeable pavers

When permeable concrete is used for a given location, the gravel base will consist of a washed #57 stone that is approximately 6 inches thick. The permeable concrete can be poured on top of this gravel base after the base has been properly compacted. If washed #57 stone is unavailable, a semi-angular to angular stone alternative can be used. Round support stone will not interlock, allowing shifts in pavement to occur, such as rocking or splitting.

When permeable block pavers or plastic grid pavements are used for the BMP, 4 inches of washed #57 stone can act as the gravel base that lays on top of the in situ soil; however, the pavers must sit on a bedding layer of smaller stone. This bedding layer should be made of washed #78 stone and be approximately 2 inches thick. This #78 stone should also be used to fill any voids present in between the permeable paver blocks after they are installed. (Figure 10.6).

Figure 10.6 Filling permeable paver voids with gravel

10.3.5 Permeable Pavement Sizing Criteria

The permeable pavement BMPs used as part of the CCAP will treat no more than 2 times their surface area. No real sizing criteria is required for these systems as part of the CCAP program. The square footage of the permeable pavement lot will generally be the same as the square footage of impervious area that was removed. The thickness of the permeable pavers is determined by the manufacturer (normally approximately 3.25 inches). Plastic grid pavers tend to be 2 inches thick. The permeable concrete should be poured to a thickness of 6 inches.

10.4 Permeable Pavement Construction

Due to the scale of many permeable pavement installations, it is recommended that a certified permeable pavement contractor install permeable pavements. Installing permeable concrete or permeable block pavers requires some experience and expertise and should not be attempted by the general public. A list of professionals who are certified to install permeable interlocking concrete pavers (PICP) and concrete grid pavers (CGP) is available from the Interlocking Concrete Pavement Institute (ICPI) at http://www.icpi.org. Carolinas Ready Mixed Concrete Association (CRMCA) can be contacted for a list of professionals with experience in installing permeable concrete (www.crmca.com). The only exception to this would be small, backyard patios that will be installed using permeable block pavers. In such an installation, traffic load will be minimal and the result of a structure failure will not be dangerous to human health and well being.

The construction steps below can be completed by a responsible, experienced contractor with minimal instruction. The key points from each section should be conveyed to the contractor, and a SWCD staff member should be on site during construction.

10.4.1 Soil excavation

For permeable pavement to be used as part of the CCAP, some amount of impervious removal must be performed. After the impervious area has been removed (likely an impervious driveway, sidewalk, parking pad, or patio) the site excavation can commence.

Excavation depth should be measured from the soil surface down. No fill should be used to bring the surrounding soil to the top of pavement level. Whenever possible, the excavated area should not be driven on by any construction equipment. This is preferable, as the soils can be compacted when exposed to heavy machinery, reducing their infiltration capability.

During the construction, a SWCD staff member should be on site to verify that the excavated area is brought to the correct depth. A survey instrument (such as a level) would be beneficial for this process. Additionally, survey measurements can be made within the excavated area to ensure that it is relatively flat (<0.5%).

10.4.2 Gravel base

The gravel base should be applied after the area has been excavated to the correct depth. Again, washed (or double washed) stone should be used for any permeable pavement installation. The gravel base installation will vary slightly depending on whether permeable concrete or permeable pavers are being installed.

If permeable concrete is being installed, a 6-inch layer of washed #57 stone can be placed in the excavated area. The stone should be spread and leveled to the appropriate slope. The stone should then be compacted with a minimum 10 ton static roller (at least 4 passes). The stone should be compacted until there is no visible movement within the gravel base. (Smith, 2000)

If permeable pavers are being installed, the same procedure that is described for the permeable concrete gravel base would be performed with a 4-inch thick layer of washed #57 stone. Next, a 2 inch layer of #78 stone should be added to the top of the #57 stone layer. This layer should be compacted using the same process that was used for the first layer.

The gravel base will now be structurally ready to support permeable pavement.

10.4.3 Concrete edging

When permeable interlocking concrete pavers are installed, some edging will be required to keep the pavers stable along the edges of the new permeable area. As stated in section 10.3.3, a 6-inch wide, 18-inch deep concrete curb should be sufficient. The framing for the curb should be constructed before the compaction of the gravel takes place. The curbing should simply run along the perimeter of the permeable area to provide support to the pavers on the edge of the lot.

10.4.4 Permeable pavement installation

As stated above, installing permeable concrete or permeable pavers should be performed by a professional familiar with their installation.

The methods used to install permeable concrete vary from those used to install standard concrete. Because permeable pavement contains void spaces which allow stormwater to infiltrate, the integrity of these pores must be maintained. Vibratory screens (such as those used in some cases to compact standard concrete) should not be used during permeable concrete installation. Such instruments can smear the surface of the concrete, resulting in reduced or restricted infiltration. Additionally, concrete vibrators, employed to reduce air pockets, are not to be used. A heavy steel roller is used in place to provide adequate compaction without smearing the concrete. Finishing exercises such as floating and brooming are not necessary and could result in surface sealing on the lot. Permeable concrete does not contain the same curing compounds as traditional concrete; thus, plastic is placed over the concrete for a number of days to prevent drying (Ferguson, 2005). The plastic should never be drug across the pavement, as smearing could result. These are a few of the differences between traditional and permeable concrete installation. While seemingly minimal, the system will be ineffective if these differences are not addressed.

Installing permeable block pavers is similar to installing regular block pavers; the difference in these systems is that voids are maintained between the pavers, allowing water to infiltrate. The blocks are placed on top of the compacted #78 stone. Once set into place, the blocks are compacted before additional #78 stone is added to the top of the pavement area and allowed to fall into the voids in between the permeable paver blocks. Excess #78 stone is swept off of the area and the permeable paver blocks are compacted one final time. Tight placement of the blocks is essential to maintaining the structural integrity of the system (Smith, 2000).

10.5 Permeable Pavement Maintenance

Like any other BMP, permeable pavements require maintenance to be effective over time. The greatest concern related to these systems is clogging of the surface void spaces. Once these surface voids become clogged, the system loses its function and effectively becomes an impervious area.

One means of removing sediment and debris from the permeable pavement area is to vacuum and sweep the area. On most commercial sites, this can be done easily by running a vacuum truck over the area. This may not be possible in a backyard BMP setting; however, the site should be swept regularly and cleared of all debris. As mentioned in section 10.4.5, the area around the permeable pavement lot should continually be evaluated to verify that sediment from adjoining areas is not washing onto the permeable pavement areas. This sediment can clog the permeable pavement over time. Additionally, any weeds or mosses that grow in the pavement voids can be removed using herbicide or be flamed.

Lastly, over time, the stone that is used to fill the voids in between the permeable pavements can be lost as tires track it off of the lot and as the gravel settles. This rock should be replaced periodically to restore the proper amount of gravel in the void spaces. Table 10.1 shows the maintenance activities associated with permeable pavements and the frequency with which these activities should take place.

Table 10.1 Permeable Pavement Maintenance Activities

Activity	Frequency
Sweeping and vacuuming	Monthly
Gravel replacement	Semi-annually initially, less frequently with time
Avoidance of landscape debris (leaves, grass clippings)	During landscape maintenance
Spray weeds and mosses with herbicide	Monthly
Observe adjoining area for sediment deposition	Continually

11.0 References:

Bean, E.Z. 2005. A Field Study to Evaluate Permeable Pavement Surface Infiltration Rates, Runoff Quantity, Runoff Quality, and Exfiltrate Quality. M.S. thesis. Raleigh, NC: Biological and Agricultural Engineering Department, North Carolina State University.

Bedient, P.B., and W.C. Huber. 1992. Hydrology and Floodplain Analysis, 2nd Edition, Reading, Massachusetts: Addison-Wesley Publishing Company.

Butler, J.D., and T. Caudill. 2005. Citizen's Guide to Protecting Wilmington's Waterways. City of Wilmington, NC: Storm Water Services.

Donaldson, Susan. 2007. The Effects of Urbanization on the Water Cycle. Nevada Cooperative Extension. Fact Sheet 04-43.

Ferguson, B.K., ed. 2005. Porous Pavements. Boca Raton, FL: CRC Press LLC.

Flint, K.R. and A.P. Davis. 2007. Pollutant Mass Flushing Characterization of Highway Stormwater Runoff from an Ultra Urban Area. Journal of Environmental Engineering 133(6): 616-626.

Hathaway, J.M., and W.F. Hunt. 2006. Stormwater BMP Costs: Division of Soil and Water Conservation Community Conservation Assistance Program. Raleigh, NC: Biological and Agricultural Engineering Department – North Carolina State University.

Leopold, L.B. 1968. Hydrology for Urban Land Planning, U.S. Geological Survey, Circular 544.

North Carolina Division of Water Quality. Stormwater Unit: What is Stormwater?. http://h2o.enr.state.nc.us/su/what_is_stormwater.htm (Accessed April 2, 2007).

Richardson, J.L., and M.J. Vepraskas, eds. 2001. Wetland Soils: Genesis, Hydrology, Landscapes, and Classification. Boca Raton, FL: CRC Press LLC.

Sansalone, J.J., and C.M. Cristina. 2004. First Flush Concepts for Suspended and Dissolved Solids in Small Impervious Watersheds. Journal of Environmental Engineering 130(11): 1301-1314.

Schueler, T.R., and H.K. Holland, eds. 2000. The Practice of Watershed Protection. Ellicott City, MD: Center for Watershed Protection.

Schueler, T. 1987. Controlling Urban Runoff – A practical Manual for Planning and Designing Urban Best Management Practices. Metropolitan Washington Council of Governments. Washington, DC 240 pp.

Smith, D.R. 2000. Permeable Interlocking Concrete Pavements: Selection, Design, Construction, Maintenance. 2nd edition, Washington, DC: Interlocking Concrete Pavement Institute.

APPENDIX A

Flow Calculations and Associated Weir Sizing for Sample Watersheds

Assumptions:

1. *Assume C value for impervious areas is 0.95*
2. *Assume C value for pervious areas is 0.25*
3. *Assume 6 inch driving head*
4. *Use 10-year, 5 minute intensity*
5. *Based on Equations 3-4, 3-5, and 3-6*

Table A1 – A4 use a rainfall intensity of 6.5 in/hr – These calculations should only be used for Asheville

Table A1 Flow calculations and suggested weir length – 1-acre watershed, various watershed scenarios – intensity of 6.5 in/hr

Impervious %	Pervious %	Equivalent C	Q (cfs)	Weir Required (ft)	Weir Suggestion (ft)
5	95	0.29	1.9	1.7	2.0
10	90	0.32	2.1	2.0	2.0
15	85	0.36	2.3	2.2	2.0
20	80	0.39	2.5	2.4	2.5

Table A2 Flow calculations and suggested weir length – 3/4-acre watershed, various watershed scenarios – intensity of 6.5 in/hr

Impervious %	Pervious %	Equivalent C	Q (cfs)	Weir Required (ft)	Weir Suggestion (ft)
5	95	0.29	1.4	1.3	1.5
10	90	0.32	1.6	1.5	1.5
15	85	0.36	1.7	1.6	1.5
20	80	0.39	1.9	1.8	2.0
25	75	0.43	2.1	2.0	2.0

Table A3 Flow calculations and suggested weir length – 1/2-acre watershed, various watershed scenarios – intensity of 6.5 in/hr

Impervious %	Pervious %	Equivalent C	Q (cfs)	Weir Required (ft)	Weir Suggestion (ft)
5	95	0.29	0.9	0.9	1.0
10	90	0.32	1.0	1.0	1.0
15	85	0.36	1.2	1.1	1.0
20	80	0.39	1.3	1.2	1.0
25	75	0.43	1.4	1.3	1.5
30	70	0.46	1.5	1.4	1.5

Table A4 Flow calculations and suggested weir length – 1/4-acre watershed, various watershed scenarios – intensity of 6.5 in/hr

Impervious %	Pervious %	Equivalent C	Q (cfs)	Weir Required (ft)	Weir Suggestion (ft)
10	90	0.32	0.5	0.5	1.0
15	85	0.36	0.6	0.5	1.0
20	80	0.39	0.6	0.6	1.0
25	75	0.43	0.7	0.7	1.0
30	70	0.46	0.7	0.7	1.0
35	65	0.50	0.8	0.8	1.0
40	60	0.53	0.9	0.8	1.0

Table A5 – A8 use a rainfall intensity of 7.2 in/hr – These calculations should only be used for Charlotte, Greensboro, Winston-Salem, Raleigh, and Durham

Table A5 Flow calculations and suggested weir length – 1-acre watershed, various watershed scenarios – intensity of 7.2 in/hr

Impervious %	Pervious %	Equivalent C	Q (cfs)	Weir Required (ft)	Weir Suggestion (ft)
5	95	0.29	2.1	1.9	2.0
10	90	0.32	2.3	2.2	2.0
15	85	0.36	2.6	2.4	2.5
20	80	0.39	2.8	2.6	2.5

Table A6 Flow calculations and suggested weir length – 3/4-acre watershed, various watershed scenarios – intensity of 7.2 in/hr

Impervious %	Pervious %	Equivalent C	Q (cfs)	Weir Required (ft)	Weir Suggestion (ft)
5	95	0.29	1.5	1.5	1.5
10	90	0.32	1.7	1.6	1.5
15	85	0.36	1.9	1.8	2.0
20	80	0.39	2.1	2.0	2.0
25	75	0.43	2.3	2.2	2.0

Table A7 Flow calculations and suggested weir length – 1/2-acre watershed, various watershed scenarios – intensity of 7.2 in/hr

Impervious %	Pervious %	Equivalent C	Q (cfs)	Weir Required (ft)	Weir Suggestion (ft)
5	95	0.29	1.0	1.0	1.0
10	90	0.32	1.2	1.1	1.0
15	85	0.36	1.3	1.2	1.0
20	80	0.39	1.4	1.3	1.5
25	75	0.43	1.5	1.4	1.5
30	70	0.46	1.7	1.6	1.5

Table A8 Flow calculations and suggested weir length – 1/4-acre watershed, various watershed scenarios – intensity of 7.2 in/hr

Impervious %	Pervious %	Equivalent C	Q (cfs)	Weir Required (ft)	Weir Suggestion (ft)
10	90	0.32	0.6	0.5	1.0
15	85	0.36	0.6	0.6	1.0
20	80	0.39	0.7	0.7	1.0
25	75	0.43	0.8	0.7	1.0
30	70	0.46	0.8	0.8	1.0
35	65	0.50	0.9	0.8	1.0
40	60	0.53	1.0	0.9	1.0

Table A9 – A12 use a rainfall intensity of 8.0 in/hr – These calculations should only be used for Fayetteville, Elizabeth City, and Greenville

Table A9 Flow calculations and suggested weir length – 1-acre watershed, various watershed scenarios – intensity of 8.0 in/hr

Impervious %	Pervious %	Equivalent C	Q (cfs)	Weir Required (ft)	Weir Suggestion (ft)
5	95	0.29	2.3	2.1	2.0
10	90	0.32	2.6	2.4	2.5
15	85	0.36	2.8	2.7	3.0
20	80	0.39	3.1	2.9	3.0

Table A10 Flow calculations and suggested weir length – 3/4-acre watershed, various watershed scenarios – intensity of 8.0 in/hr

Impervious %	Pervious %	Equivalent C	Q (cfs)	Weir Required (ft)	Weir Suggestion (ft)
5	95	0.29	1.7	1.6	1.5
10	90	0.32	1.9	1.8	2.0
15	85	0.36	2.1	2.0	2.0
20	80	0.39	2.3	2.2	2.5
25	75	0.43	2.6	2.4	2.5

Table A11 Flow calculations and suggested weir length – 1/2-acre watershed, various watershed scenarios – intensity of 8.0 in/hr

Impervious %	Pervious %	Equivalent C	Q (cfs)	Weir Required (ft)	Weir Suggestion (ft)
5	95	0.29	1.1	1.1	1.0
10	90	0.32	1.3	1.2	1.5
15	85	0.36	1.4	1.3	1.5
20	80	0.39	1.6	1.5	1.5
25	75	0.43	1.7	1.6	1.5
30	70	0.46	1.8	1.7	2.0

Table A12 Flow calculations and suggested weir length – 1/4-acre watershed, various watershed scenarios – intensity of 8.0 in/hr

Impervious %	Pervious %	Equivalent C	Q (cfs)	Weir Required (ft)	Weir Suggestion (ft)
10	90	0.32	0.6	0.6	1.0
15	85	0.36	0.7	0.7	1.0
20	80	0.39	0.8	0.7	1.0
25	75	0.43	0.9	0.8	1.0
30	70	0.46	0.9	0.9	1.0
35	65	0.50	1.0	0.9	1.0
40	60	0.53	1.1	1.0	1.0

Table A13 – A16 use a rainfall intensity of 9.7 in/hr – These calculations should only be used for Wilmington

Table A13 Flow calculations and suggested weir length – 1-acre watershed, various watershed scenarios – intensity of 9.7 in/hr

Impervious %	Pervious %	Equivalent C	Q (cfs)	Weir Required (ft)	Weir Suggestion (ft)
5	95	0.29	2.8	2.6	2.5
10	90	0.32	3.1	2.9	3.0
15	85	0.36	3.4	3.2	3.0
20	80	0.39	3.8	3.6	3.5

Table A14 Flow calculations and suggested weir length – 3/4-acre watershed, various watershed scenarios – intensity of 9.7 in/hr

Impervious %	Pervious %	Equivalent C	Q (cfs)	Weir Required (ft)	Weir Suggestion (ft)
5	95	0.29	2.1	2.0	2.0
10	90	0.32	2.3	2.2	2.5
15	85	0.36	2.6	2.4	2.5
20	80	0.39	2.8	2.7	3.0
25	75	0.43	3.1	2.9	3.0

Table A15 Flow calculations and suggested weir length – 1/2-acre watershed, various watershed scenarios – intensity of 9.7 in/hr

Impervious %	Pervious %	Equivalent C	Q (cfs)	Weir Required (ft)	Weir Suggestion (ft)
5	95	0.29	1.4	1.3	1.5
10	90	0.32	1.6	1.5	1.5
15	85	0.36	1.7	1.6	1.5
20	80	0.39	1.9	1.8	2.0
25	75	0.43	2.1	1.9	2.0
30	70	0.46	2.2	2.1	2.0

Table A16 Flow calculations and suggested weir length – 1/4-acre watershed, various watershed scenarios – intensity of 9.7 in/hr

Impervious %	Pervious %	Equivalent C	Q (cfs)	Weir Required (ft)	Weir Suggestion (ft)
10	90	0.32	0.8	0.7	1.0
15	85	0.36	0.9	0.8	1.0
20	80	0.39	0.9	0.9	1.0
25	75	0.43	1.0	1.0	1.0
30	70	0.46	1.1	1.1	1.0
35	65	0.50	1.2	1.1	1.5
40	60	0.53	1.3	1.2	1.5

APPENDIX B

Outlet Construction – Wooden Weir Control Structure

Figure B1 is a diagram of a wooden weir control structure. This type of structure can be used to control ponding depth, drawdown rate and depth of outflow from a variety of devices, including wetlands and rain gardens. Only lumber treated for at least in-ground use should be selected. Do not use CCA treated lumber. Stainless steel fasteners are recommended. The structure can be installed as follows:

1) Dig a trench 2 to 3 feet wide and long and deep enough for the weir. Each side of the weir should extend at least 18 inches into the adjacent bank and 18 inches below final grade at the base of the weir.

2) Two or 4 posts can be used to stabilize the structure, depending on the length of the weir. The posts can be 4x4 or 4x6, depending on the BMP size, although 4x4 will be sufficient in most cases. Points can be cut on the tips of the posts and they can be driven into the ground at the bottom of the trench. If they can not be driven sufficiently, post holes can be dug and backfilled with concrete. Use a string line to make sure the posts are aligned.

3) Flashboards can then be nailed or screwed to the posts, starting from the bottom and working up. Check the level on the boards. Caulk between each board. Leave a weir opening near the top of the flashboard wall as necessary.

4) An additional board or metal plate can be nailed or screwed to the flashboards and used to adjust ponding depth – rather than having to modify the flashboard structure – and/or as an adjustable orifice plate for wetlands. If a metal plate is used, consider any safety issues with sharp edges.

5) Proper backfill around the structure is very important to keep it from washing out during the first large storm event. Soil should be added in small lifts (4-6 inches) and compacted with each lift. If the space is too small for power equipment, the top of a sledge hammer works well or the end of a shovel handle for even smaller spaces. The surface of the compacted soil can be further protected using filter fabric and stone or rip-rap, as necessary.

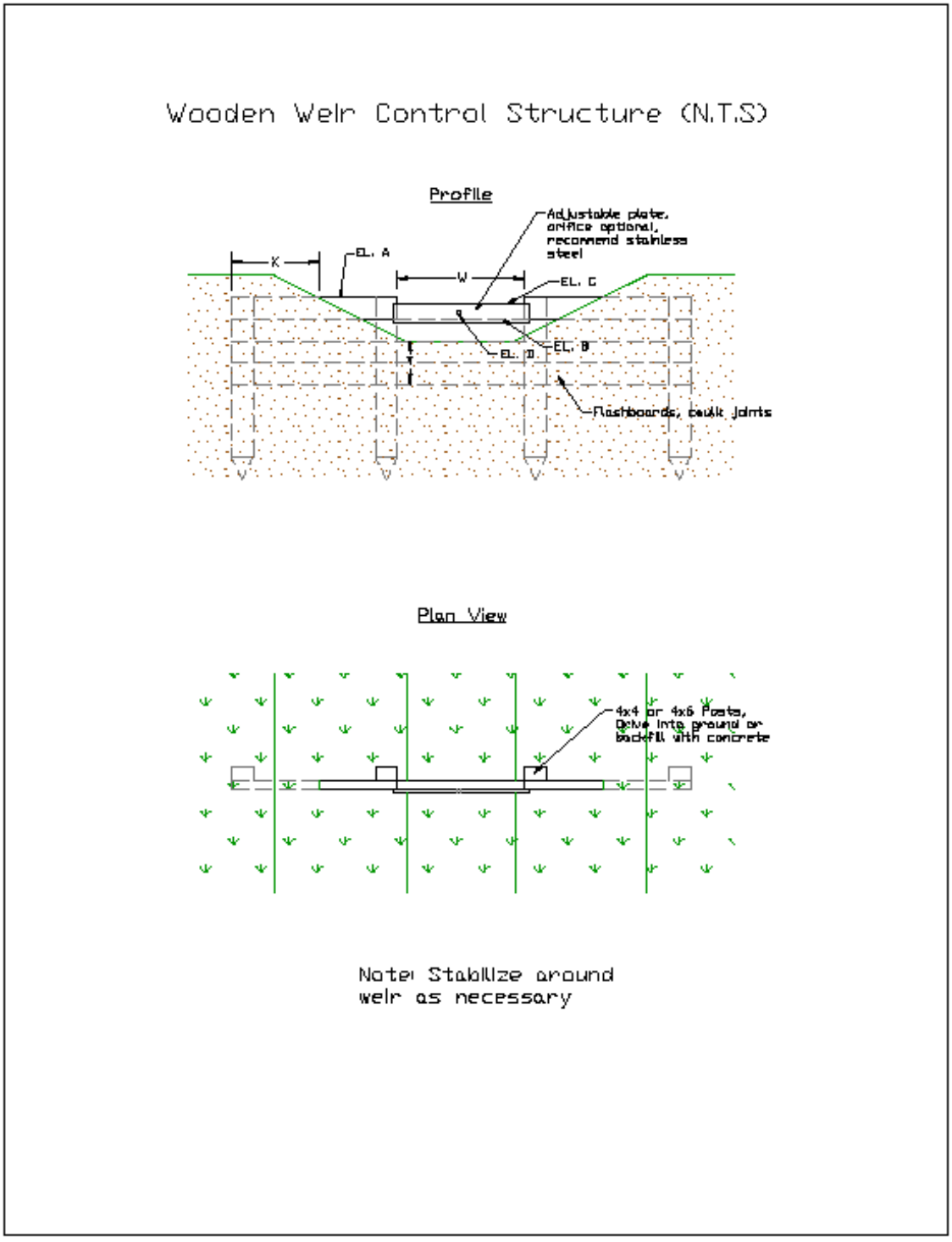


Figure B1 Diagram of a wooden weir control structure

APPENDIX C

Level Spreader Design, Construction, and Maintenance

URBAN Waterways

Level Spreaders: Overview, Design, and Maintenance

Level spreaders are stormwater structures that can support the filtering action of riparian buffers if designed and installed properly.

This publication presents the latest research findings on level spreaders in North Carolina and describes recommended practices for designing, installing, and maintaining these structures.

Since 1998, North Carolina has implemented rules to protect riparian buffers in several major river basins. These rules require that concentrated stormwater runoff be diffused, or spread, prior to discharge into a riparian area. To accomplish this, the Division of Water Quality (DWQ) in the N.C. Department of Environment and Natural Resources (NCDENR) recommended the use of level spreaders and developed initial design standards in October 2001. An overview of level spreaders and riparian buffers can be found in *Urban Stormwater Structural Best Management Practices*, AG-588-01, of the Urban Waterways series. This fact sheet provides more detailed information on designing, installing, and maintaining level spreaders.

Distributed in furtherance of the acts of Congress of May 8 and June 30, 1914. North Carolina State University and North Carolina A&T State University commit themselves to positive action to secure equal opportunity regardless of race, color, creed, national origin, religion, sex, age, or disability. In addition, the two Universities welcome all persons without regard to sexual orientation. North Carolina State University, North Carolina A&T State University, U.S. Department of Agriculture, and local governments cooperating.

NC STATE UNIVERSITY A&T STATE UNIVERSITY COOPERATIVE EXTENSION
Helping People Put Knowledge to Work

DIFFUSE FLOW: WHAT IS IT?

Diffuse flow, sometimes called *sheet flow*, occurs when water spreads out evenly across an area (Figure 1). In contrast, when stormwater collects in a drainage system and flows to a stream via a pipe, swale, or ditch, it does not make enough contact with or bypasses the *riparian buffer*—a vegetated area along streams, rivers, and other water bodies that helps to filter runoff and prevent erosion. Riparian buffers can improve water quality in urban environments by reducing stormwater peak flow, reducing runoff volume through infiltration, and removing nutrients and sediment through physical and biological processes. They are most effective, however, when stormwater flows through them at a shallow, uniform depth—the diffuse flow that well-designed level spreaders can provide.

LEVEL SPREADER SYSTEMS: AN OVERVIEW

Level spreader systems consist of three parts: the forebay, the channel, and the riparian buffer (Figure 2).

Figure 1. A level spreader providing diffuse flow (Frank Hahne, Mecklenburg County)

FOREBAY. The first part of the system is the forebay, which is used for the preliminary treatment of stormwater. It is an excavated, bowl-shaped feature that slows the influent stormwater and allows heavy sediment and debris to settle. The forebay may be lined with riprap to reduce erosion within the excavated area. The uneven riprap surfaces function as small sediment traps. When a level spreader is used to disperse outflow from a detention pond, a forebay may be necessary to reduce runoff velocity before the outflow reaches the level spreader.

CHANNEL. After the stormwater passes though the forebay, it enters a concrete, rock, or grassed channel—the main body of the level spreader. This is a dead-end channel because it does not directly connect the watershed to the stream. Instead, the channel is a long, shallow impoundment that fills to the level of its lower side. The lower side (the *downslope side*) of the channel is constructed so that it is level along its full length. This lower side, or *level spreader lip*, is often constructed of concrete or rock so that it resists erosion. As stormwater enters the channel, it rises until it fills the channel and exits evenly over the lip. The downslope side of the system functions as a long, broad-crested weir.

RIPARIAN BUFFER. After the stormwater passes over the level spreader lip, it enters the riparian buffer, often simply called the buffer. As the stormwater passes through the buffer vegetation, some of the water infiltrates. Ideally, the buffer will remove sediment and nutrients from runoff before it reaches the stream.

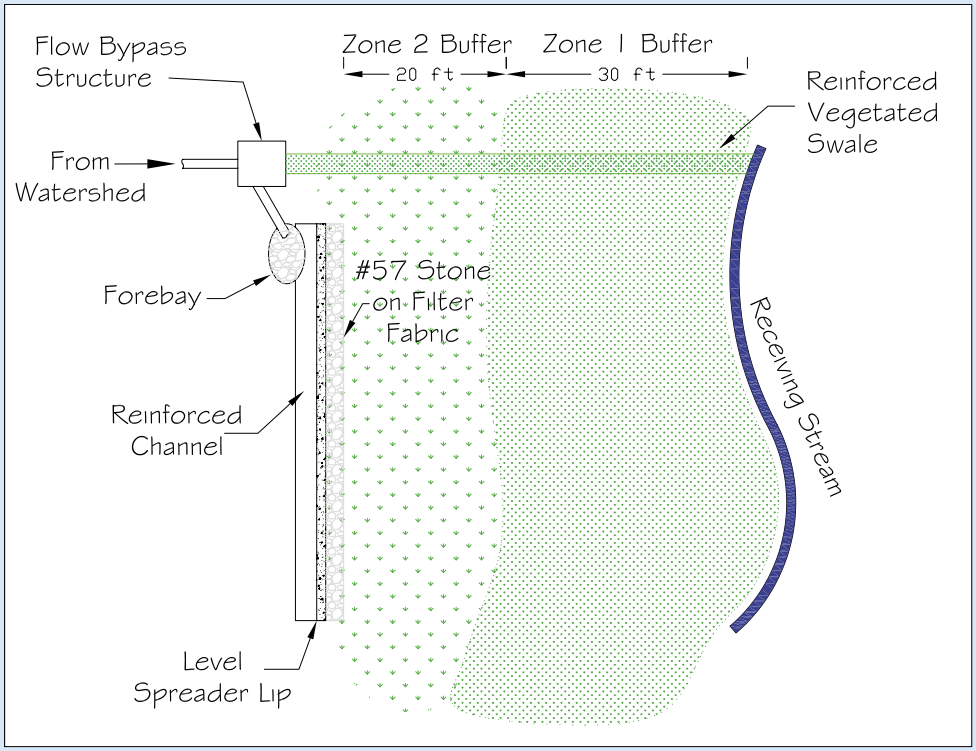


Figure 2. Level spreader system

RECENT LEVEL SPREADER RESEARCH

The Biological and Agricultural Engineering Department at North Carolina State University received a grant from NCDENR in December 2005 to evaluate level spreaders as stormwater best management practices (BMPs). The researchers visited 24 locations where level spreaders were in use and performed various qualitative and quantitative analyses.

The results of the study indicated that none of the level spreader–riparian buffer systems was able to provide diffuse flow through the riparian buffer from the level spreader to the stream. Common causes for failure to maintain diffuse flow included the following:

- Lack of maintenance.
- Poor design.
- Riparian topography, vegetation, or both .
- Poor construction methods (level spreader lip not level; channel built with easily eroded materials as in Figure 3).
- Human interference after the level spreader has been constructed.

This field evaluation indicated that level spreader systems in North Carolina would benefit from design revisions, construction guidance, and maintenance. As a result, the design guidelines developed by NCDENR in October 2001 were revisited and revised in the summer of 2006.

Figure 3. Failure at level spreader constructed with ABC stone

DESIGN RECOMMENDATIONS

Based on this research, the following recommendations should be considered when designing level spreaders.

Level spreader lip. A level spreader system obviously needs a stable lip that cannot be eroded. Concrete level spreaders can be built with minimal slope along the length of the channel's downslope side. Concrete level spreaders resist erosion better than level spreaders made of earth, gravel, or both. If a flow greater than the design flow is routed over a level spreader made of concrete, the level spreader lip will not be damaged. Level spreaders made of earth, gravel, or both should not be used in any urban applications because they routinely fail. Another stable material is a metal gutter. Like concrete level spreaders, pre-fabricated metal level spreaders can be expected to remain level with minimal maintenance.

Ideally, the lip of the concrete level spreader should be higher than the existing ground by 3 to 6 inches. This allows water to pass over the lip without interference from buffer vegetation. To limit any erosion that could occur as water falls from the top of the level spreader to the existing soil, a layer of filter fabric should be extended a distance of 3 feet from the level spreader lip towards the buffer. Stone, such as No. 57 aggregate, should be placed on top of the filter fabric (3 to 4 inches deep) to reduce erosion just downslope of the level spreader (Figure 4). A 3-foot wide strip of erosion control matting can be used in place of the filter fabric and No. 57 stone combination. However, such an area must be stable and have adequate vegetation before receiving stormwater.

Level spreader dimensions. Level spreader dimensions have a broad range, and no combination seems to be superior. The width of a level spreader, however, should be at least three times wider than the diameter of the inlet culvert. The design depth, or depth between the invert of the level spreader channel and the level spreader lip, is currently recommended to be *no less than* either 9 inches or half of the inlet culvert diameter, whichever is greater.

When discharging into a buffer with thick ground cover, there must be 13 feet of level spreader for every 1 cubic foot per second (cfs) of flow. This design specification is based on maximum flow velocities and is intended to limit erosion in the buffer. Grass, for example, is more resistant to erosion than mulch and detritus. Therefore, a shorter length of level spreader is needed upslope of grass than upslope

of mature woods. In forested buffers, this number varies based on the width of the riparian buffer. The wider the riparian buffer, particularly wooded buffers, the more stormwater will infiltrate the buffer. When infiltration within the buffer is taken into account, the length of level spreader per unit of flow can be reduced:

- A level spreader discharging onto a 50-foot wide wooded riparian buffer should be sized at 65 feet per 1 cfs of flow.
- Discharging onto a 100-foot wide wooded buffer requires 50 feet of level spreader per 1 cfs of flow.
- Discharging onto a 150-foot wide wooded buffer requires 40 feet of level spreader per 1 cfs of flow.

The minimum length of any level spreader should be 13 feet, and the maximum allowable length by DWQ standards is 130 feet. A summary of the sizing guidelines for level spreader lip length is shown in Table 1.

Table 1. Level Spreader Lip Sizing Guidelines

Riparian Buffer Vegetation	Riparian Buffer Width (ft)	Length of Level Spreader (ft per 1 cfs of flow)
Thick ground cover	For any width	13
Forested	50	65
Forested	100	50
Forested	150	40

FOREBAY INCLUSION. Forebays should be utilized in level spreader systems to dissipate energy and reduce the sediment that accumulates behind the level spreader lip (Figure 5). The forebay is essentially a bowl-shaped depression lined on the bottom and sides with Class B rip rap. The forebay should be sized so that it is at least 0.2 percent of the contributing catchment's impervious or paved surface area. The catchment is the land area draining to the system.

The depth of the forebay where the stormwater initially enters should be 3 feet. The forebay should then slope upward to a depth of 1 foot prior to discharging into the level spreader (Figure 5).

FLOW-BYPASS. If runoff from high intensity storms (those that deliver more than 1 inch of rain per hour) is allowed to flow through a level-spreader and riparian-buffer system that is not designed to handle such storms, erosion can occur within the buffer. Thus, during heavy rain storms that produce more runoff than can be infiltrated by the buffer, excess stormwater should bypass the buffer and be sent through a protected channel to a predetermined, protected stream entry point. This is achieved by allowing the runoff produced by a rainfall intensity of 1 inch per hour to enter the level spreader while diverting runoff from heavier rainfalls to the stream. The *bypass channel*, or *swale*, should employ turf reinforcement matting or rip rap.

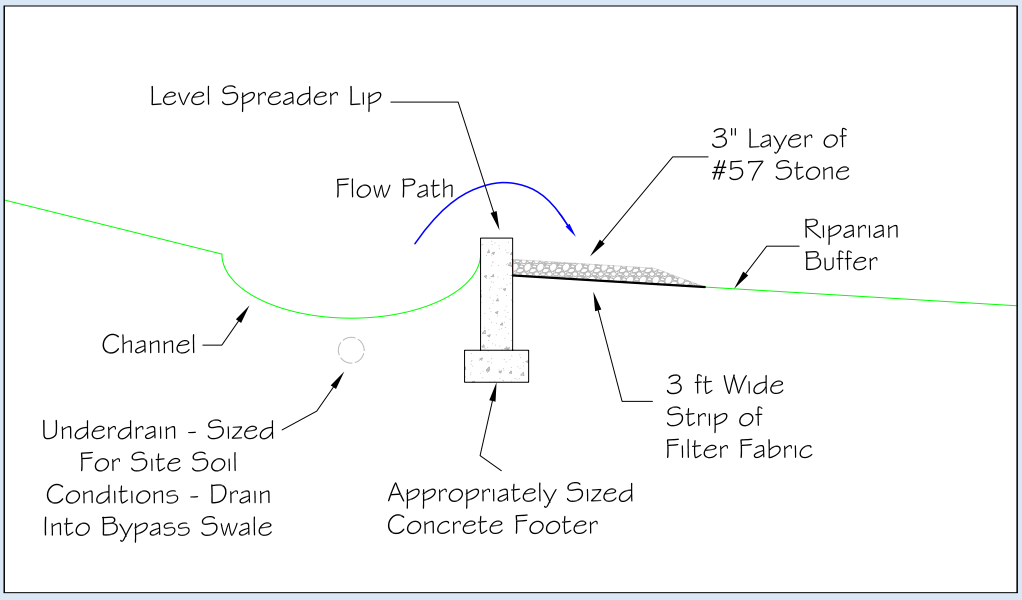

Level Spreader Lip
3" Layer of #57 Stone
Flow Path
Riparian Buffer
Channel
3 ft Wide Strip of Filter Fabric
Underdrain - Sized For Site Soil Conditions - Drain Into Bypass Swale
Appropriately Sized Concrete Footer

Figure 4. Sample cross section of a concrete level spreader

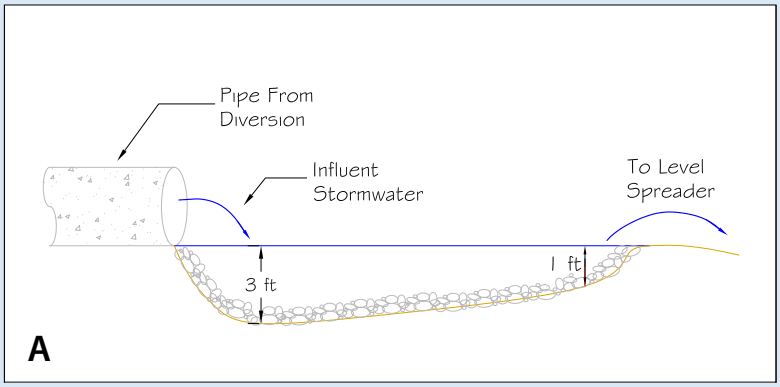


Figure 5. (A) Forebay schematic. (B) Image of level spreader with forebay

MAXIMUM SLOPE. The first 10 feet of riparian buffer downslope of the level spreader should have a slope less than or equal to 4 percent.

The overall slope of the buffer should not exceed 6 percent for wooded buffers and 8 percent for buffers containing thick ground cover (such as grass). When slopes are greater than this, other practices, such as bioretention, stormwater wetlands, and ponds, can be used to reduce peak flows and provide water quality improvements. However, on a case-by-case basis, the DWQ may approve a series of level spreaders for riparian buffer slopes of 12 to 15 percent. This approval is contingent on a site visit and the professional judgment of the DWQ permitter.

MAINTENANCE

Level spreaders require *at least* yearly maintenance to remove trees and shrubs that begin to grow on the level spreader lip or that impede flow just downslope of the level spreader (in the section of No. 57 stone from Figure 4). Any debris and sediment that build up in the level spreader, forebay, and channel should be removed annually and after storms greater than or equal to a *two-year storm*—the precipitation associated with a 24-hour storm event that occurs, on average, once every two years (Figures 6 and 7). In North Carolina, the two-year storm ranges from 3.5 to 4.25 inches over a 24-hour period. Additionally, the level spreader channel and the riparian buffer should be examined annually and after storms greater than or equal to the two-year storm for possible erosion and gulley formation.

If possible, the buffer vegetation immediately downslope of the level spreader lip should be mowed

Figure 6. Level spreader just after construction

Figure 7: Sediment and debris build-up after approximately 4.5 years of operation

regularly to encourage low, dense growth and to facilitate inspection. The use of perennial, dense, low-growing ground covers (such as common bermudagrass) downslope of the lip may help to maintain diffuse flow.

These issues should be addressed immediately to restore proper function. If erosion is apparent, corrective action must be taken, such as installing erosion control matting and possibly regrading. NCDENR must be notified before any work is performed in the protected buffer.

RIPARIAN BUFFER TOPOGRAPHY

Riparian buffers are highly variable. Depending on internal buffer topography, water will tend to re-concentrate, almost immediately in some cases. Certain level-spreader and riparian-buffer systems may only partially disperse influent concentrated flow. The systems still can improve water quality and reduce flow peaks. However, level spreaders should be situated in areas away from natural swales, depressions, and mounds where diffuse flow is more attainable. If the riparian buffer is not conducive to diffuse flow, other BMPs should be considered.

SUMMARY

Table 2 shows suggested site selection, design, and maintenance criteria for level spreader systems. Level spreader design is not as technically challenging as other stormwater BMP designs. Nevertheless, siting and installing a level spreader that functions properly is challenging. The design criteria described in this publication represent elements of good level spreader design but do not ensure overall system effectiveness. For the system to function as intended, it must be maintained, and the internal topography of the riparian buffer must be conducive to keeping flow diffuse. *Before designing a level spreader system, the designer should visit the site. This site visit is highly recommended.* If conditions are not suitable for the installation of the level spreader (for example, if the slope is too steep or adequate space is not available), other stormwater BMPs should be used.

Table 2: Level Spreader Site Selection, Design, and Maintenance Recommendations

Item	Recommendation
Level spreader lip material	A concrete or sturdy metal lip should be used in all level spreaders. The lip should be tied into the soil with an appropriately sized concrete footer or similar footer.
Level spreader lip dimensions	The concrete lip should extend 3 to 6 inches above the existing grade on the buffer side. Just after the lip, a 3-foot wide, 3- to 4-inch thick layer of No. 57 stone should be used to minimize erosion due to the water spilling over the level lip. This gravel should be laid on top of filter fabric that has been tied into the soil.
Buffer slope	Riparian buffer slopes should not exceed 8% when discharging into a densely vegetated buffer and 6% when discharging into a forested buffer. A series of level spreaders may be approved by DWQ for buffer slopes up to 12 to 15%.
Flow bypass	Only the amount of flow associated with a rainfall intensity of 1 inch/hour should be routed through the level spreader. All additional flow should be routed to the stream via a properly designed and maintained swale or pipe. Stream banks should be protected at the point where the additional flow will be discharged.
Forebay	A forebay, or some other form of pretreatment, should be a part of any level spreader design. The forebay surface area should be no less than 0.2% of the contributing catchment's impervious surface area.
Maintenance	Level spreaders should be maintained yearly and after storms greater than or equal to a two-year, 24-hour event. Sediment and debris should be removed from the forebay and from the channel behind the level lip. All trees and vegetation that grow in the section of no. 57 stone should be removed. The grass in all swales should be maintained, and the level spreader and buffer should be checked for signs of erosion. Erosion that is discovered in the buffer should be addressed through the application of erosion control mat and through re-grading if necessary. NCDENR must be notified prior to any work performed in a protected riparian buffer.

RESOURCES

Related fact sheets

in the Urban Waterways series, North Carolina Cooperative Extension, and North Carolina Agricultural Research Service Bulletins, N.C. State University:

Hunt, W. F. 2000. *Urban Stormwater Structural Best Management Practices (BMPs)* (AG-588-01). Online: http://www.bae.ncsu..edu/stormwater/PublicationFiles/UrbanBMPS199.pdf

Hunt, W. F., and L. L. Szpir. 2006. *Permeable Pavements, Green Roofs, and Cisterns: Practices for Low Impact Development* (AGW-588-06). Online: http://www.bae.ncsu.edu/stormwater/PublicationFiles/BMPs4LID.pdf

Osmond, D. L., J. W. Gilliam, and R. O. Evans. 2002. *Riparian Buffers and Controlled Drainage to Reduce Agricultural Nonpoint Source Pollution*. N.C. Agricultural Research Service Technical Bulletin 318. Online: http://www.soil.ncsu.edu/lockers/Osmond_D/web/RiparianBuffers.pdf

Related Web sites

BAE Stormwater Group
www.bae.ncsu.edu/stormwater
Highlights of stormwater research projects and Extension programs provided across North Carolina by N.C. State University's Biological and Agricultural Engineering Department.

State of North Carolina
www.stormwater.org
NCDENR's stormwater site.

http://h20.enr.state.nc.us/su/Manuals_Factsheets.htm
DWQ manuals, fact sheets, and a link to the revised level spreader design guidelines.

ACKNOWLEDGEMENTS

All photographs provided by the authors except for Figure 1, courtesy of Frank Hahne, Mecklenburg County Engineering Department.

Prepared by
Jon M. Hathaway, Extension Associate
William F. Hunt, Assistant Professor and Extension Specialist
Biological and Agricultural Engineering
North Carolina State University

Published by
NORTH CAROLINA COOPERATIVE EXTENSION SERVICE

COLLEGE OF AGRICULTURE & LIFE SCIENCES
ACADEMICS ▲ RESEARCH ▲ EXTENSION

NC STATE UNIVERSITY

AGW-588-09

E07-45839
11/2006/bs

APPENDIX D

Sizing Charts for Rain Gardens and Backyard Wetlands

Figure D1: Wetland Surface Area as a function of Watershed Size (<5000 sf) and Impervious % (1" Rainfall) 9" ponding depth

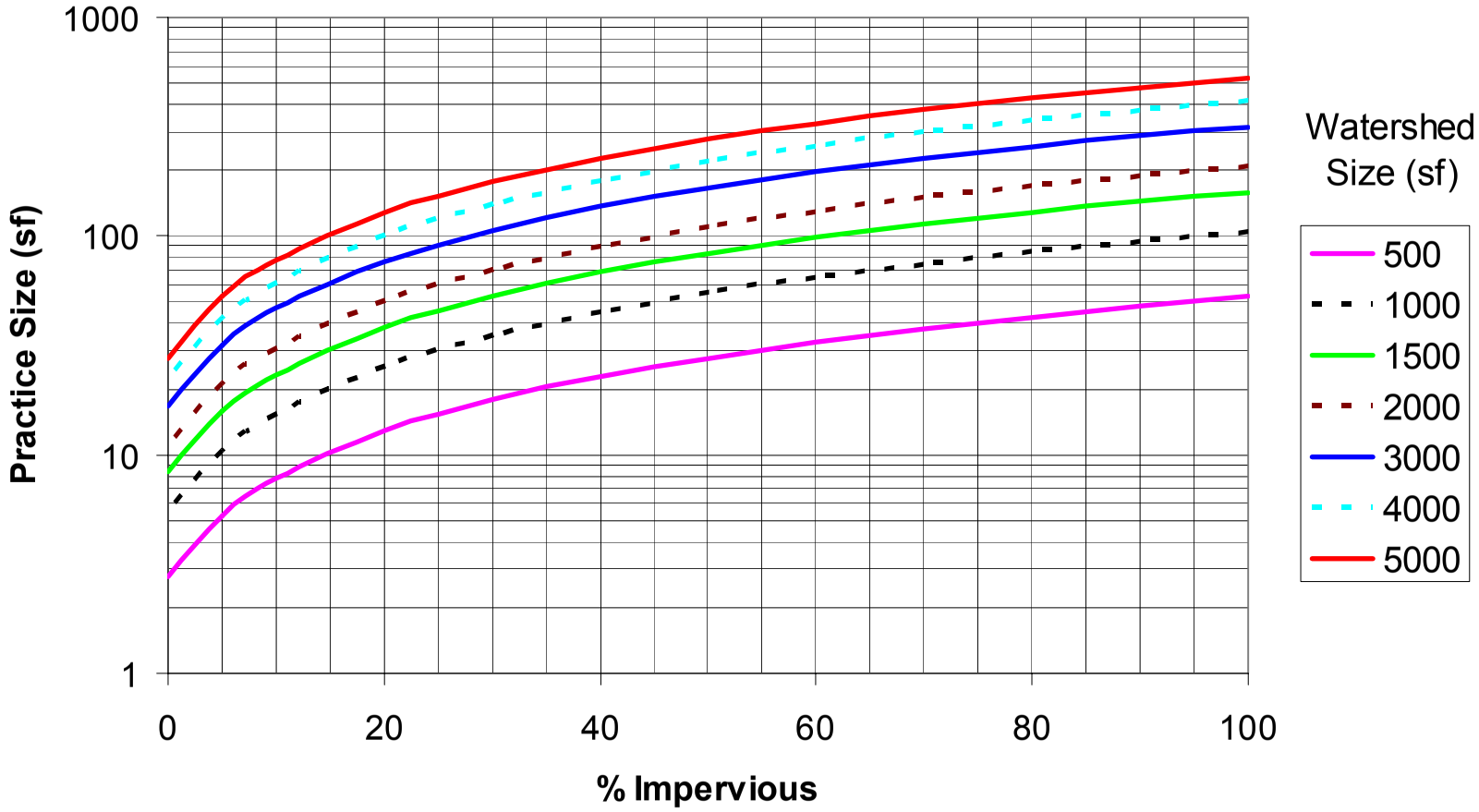
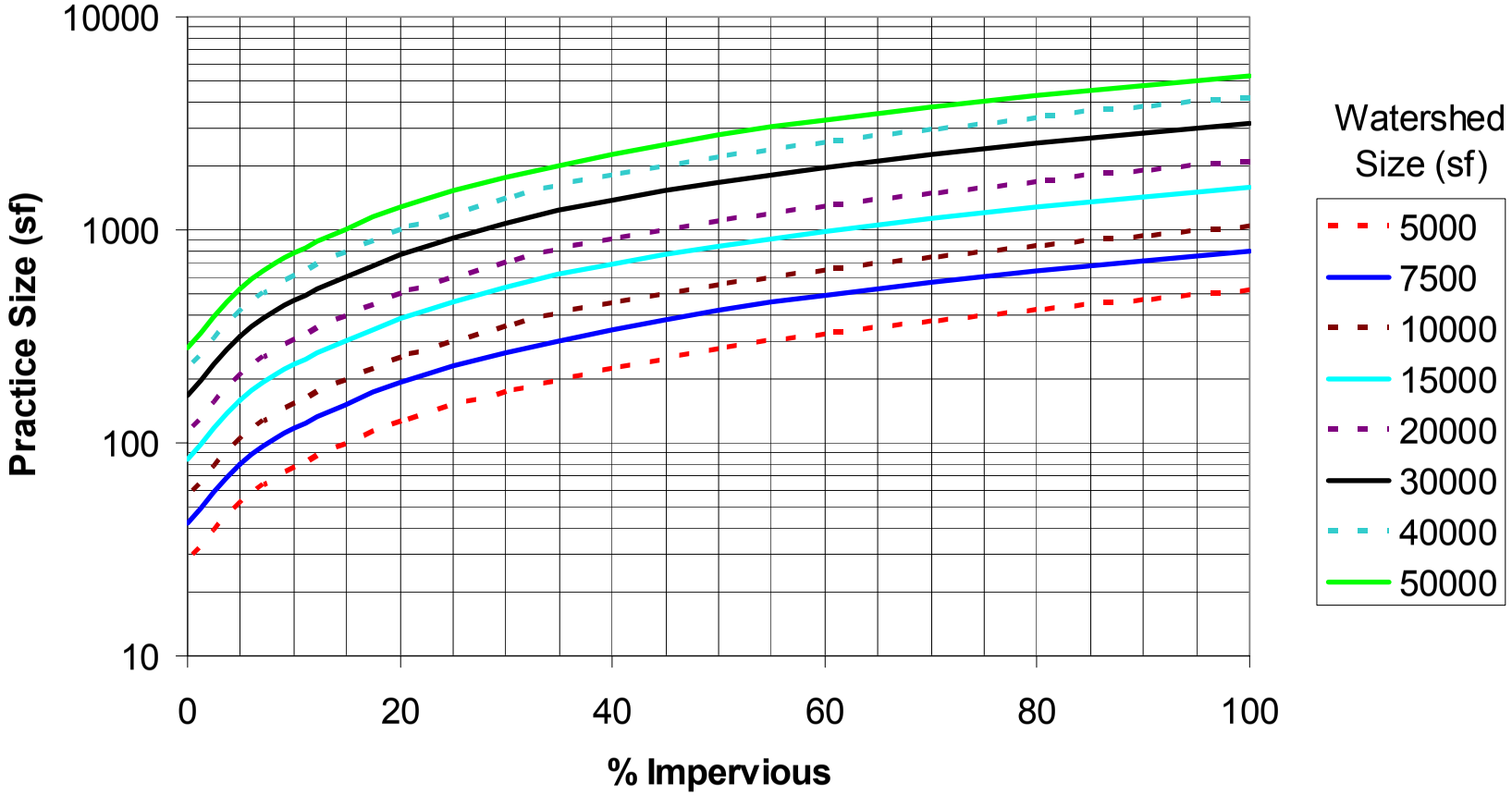


Figure D2: Wetland Surface Area as a function of Watershed Size (>5000 sf) and Impervious % (1" Rainfall) 9" ponding depth



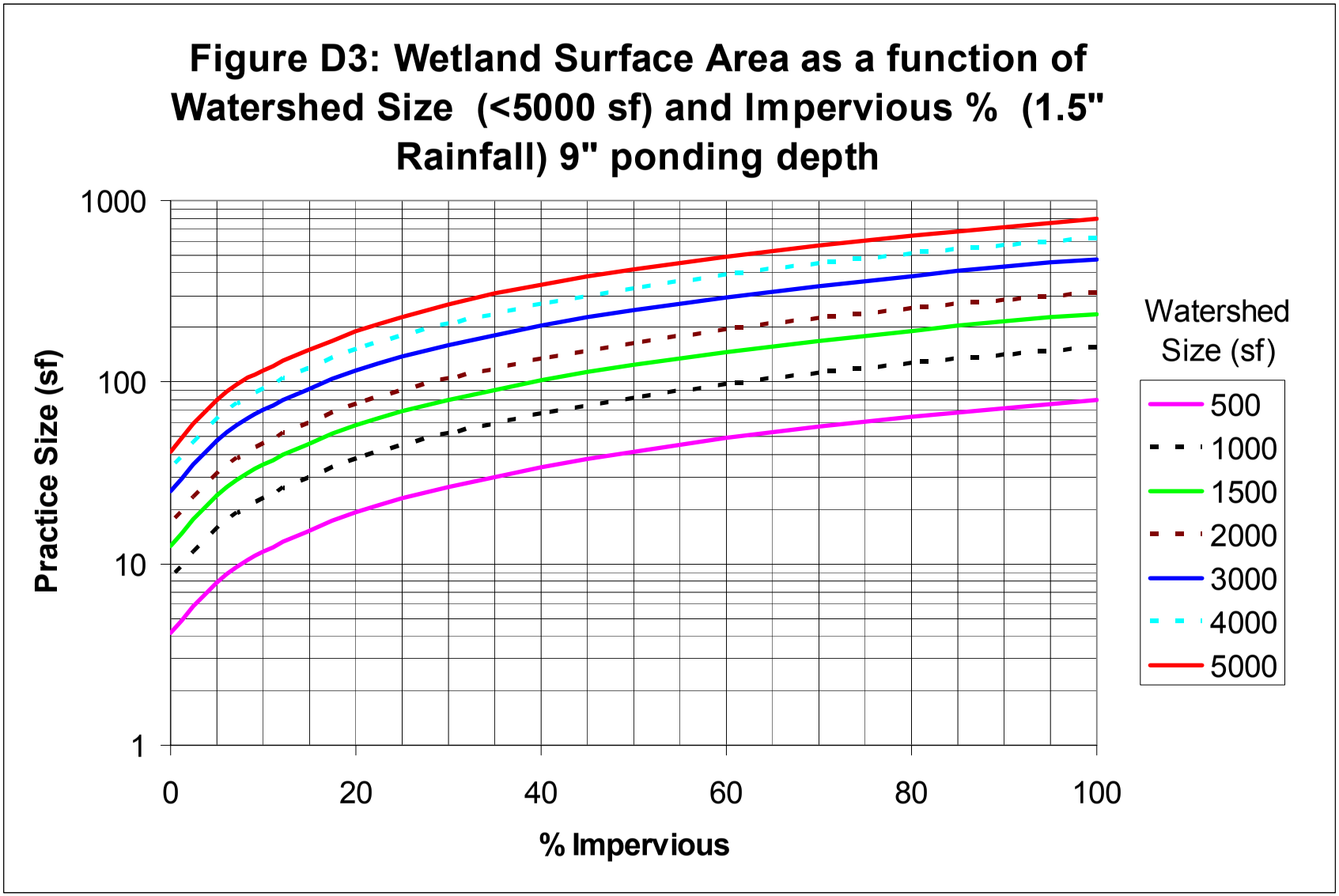


Figure D3: Wetland Surface Area as a function of Watershed Size (<5000 sf) and Impervious % (1.5" Rainfall) 9" ponding depth
Practice Size (sf)
1000
100
10
1
0
20
40
60
80
100
% Impervious
Watershed Size (sf)
500
1000
1500
2000
3000
4000
5000

Figure D4: Wetland Surface Area as a function of Watershed Size (>5000 sf) and Impervious % (1.5" Rainfall) 9" ponding depth

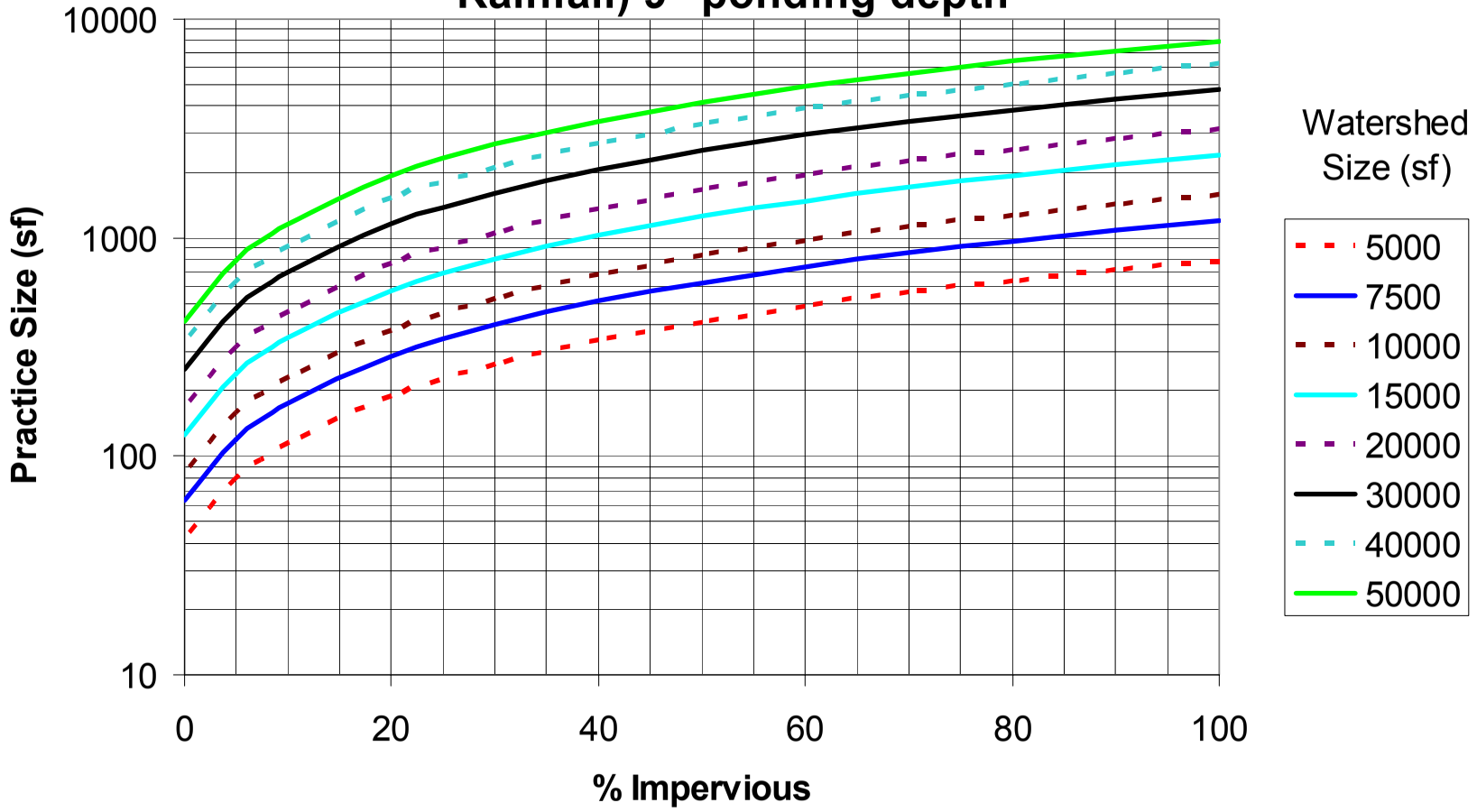


Figure D5: Wetland Surface Area as a function of Watershed Size (<5000 sf) and Impervious % (1" Rainfall) 6" ponding depth

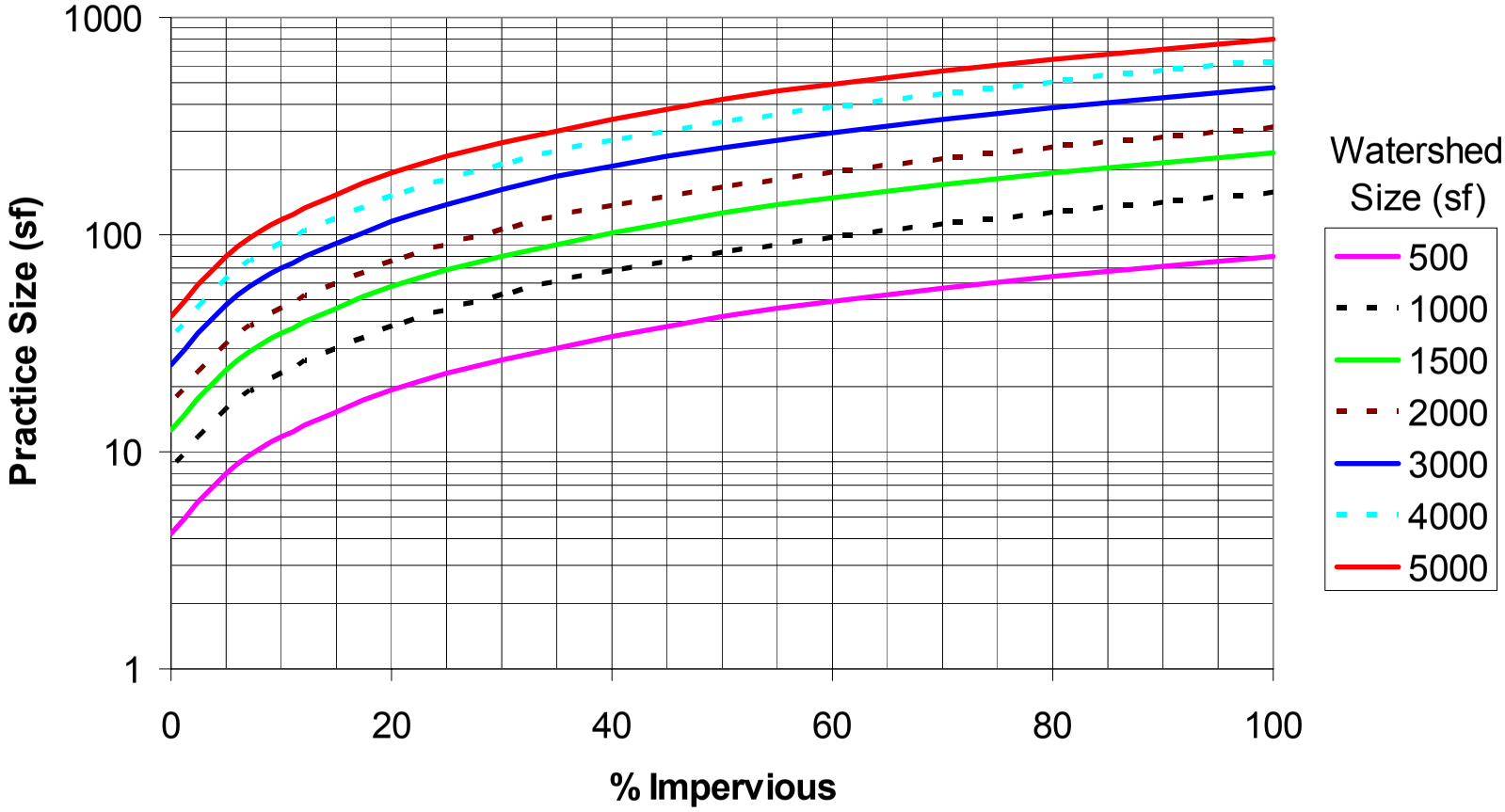


Figure D6: Wetland Surface Area as a function of Watershed Size (>5000 sf) and Impervious % (1" Rainfall) 6" ponding depth

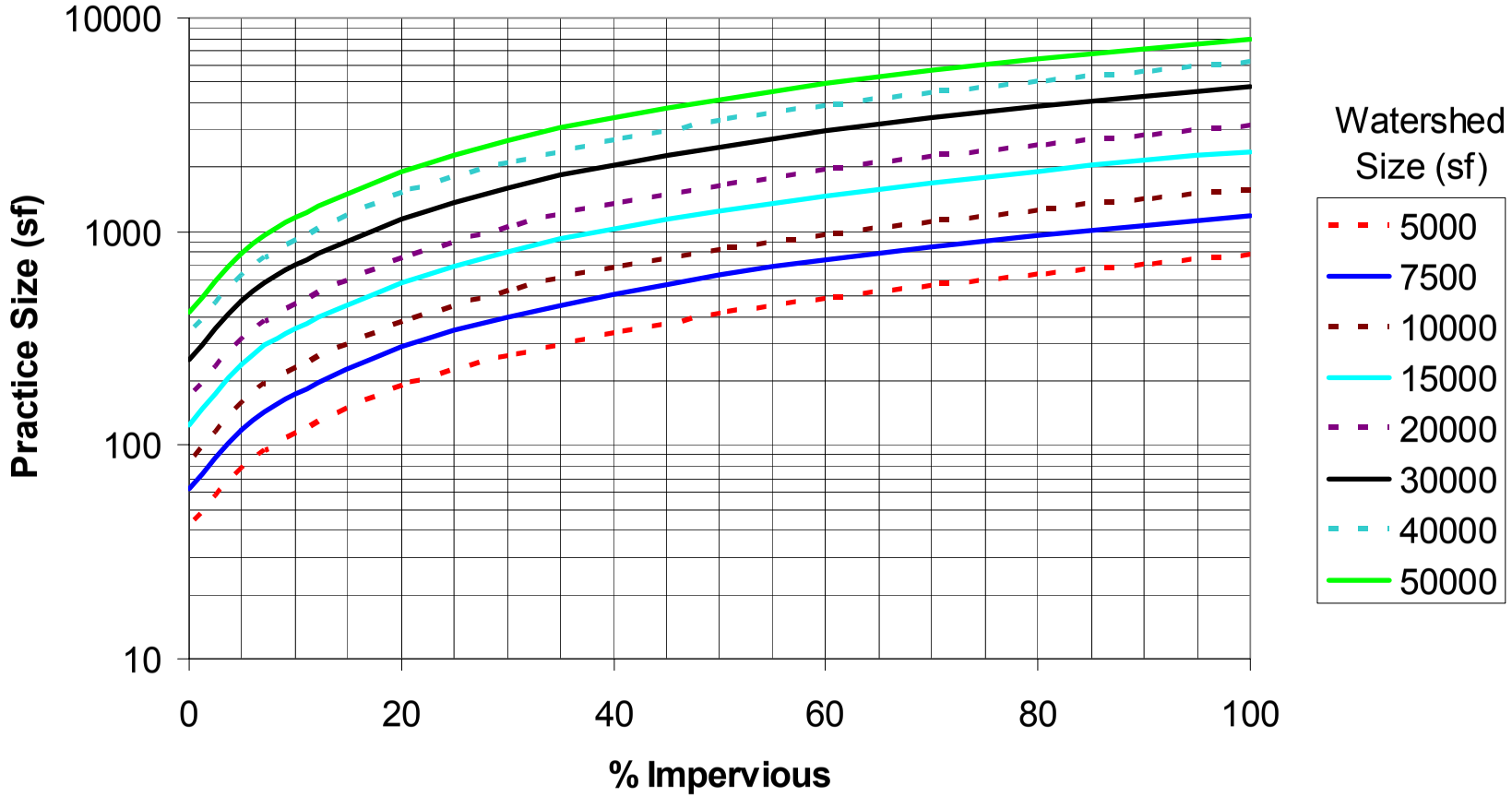


Figure D7: Wetland Surface Area as a function of Watershed Size (<5000 sf) and Impervious % (1.5" Rainfall) 6" ponding depth

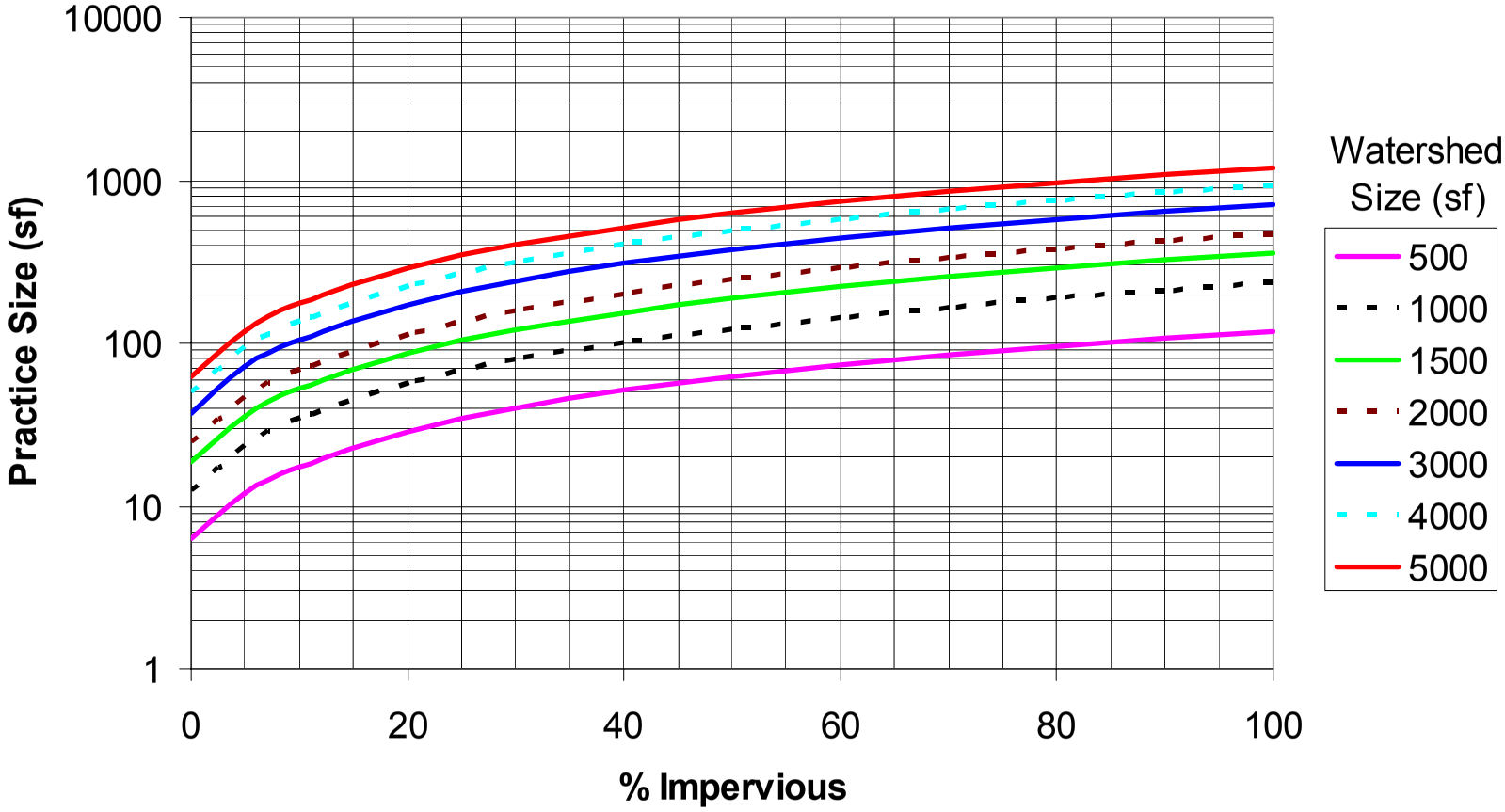


Figure D8: Wetland Surface Area as a function of Watershed Size (>5000 sf) and Impervious % (1.5" Rainfall) 6" ponding depth

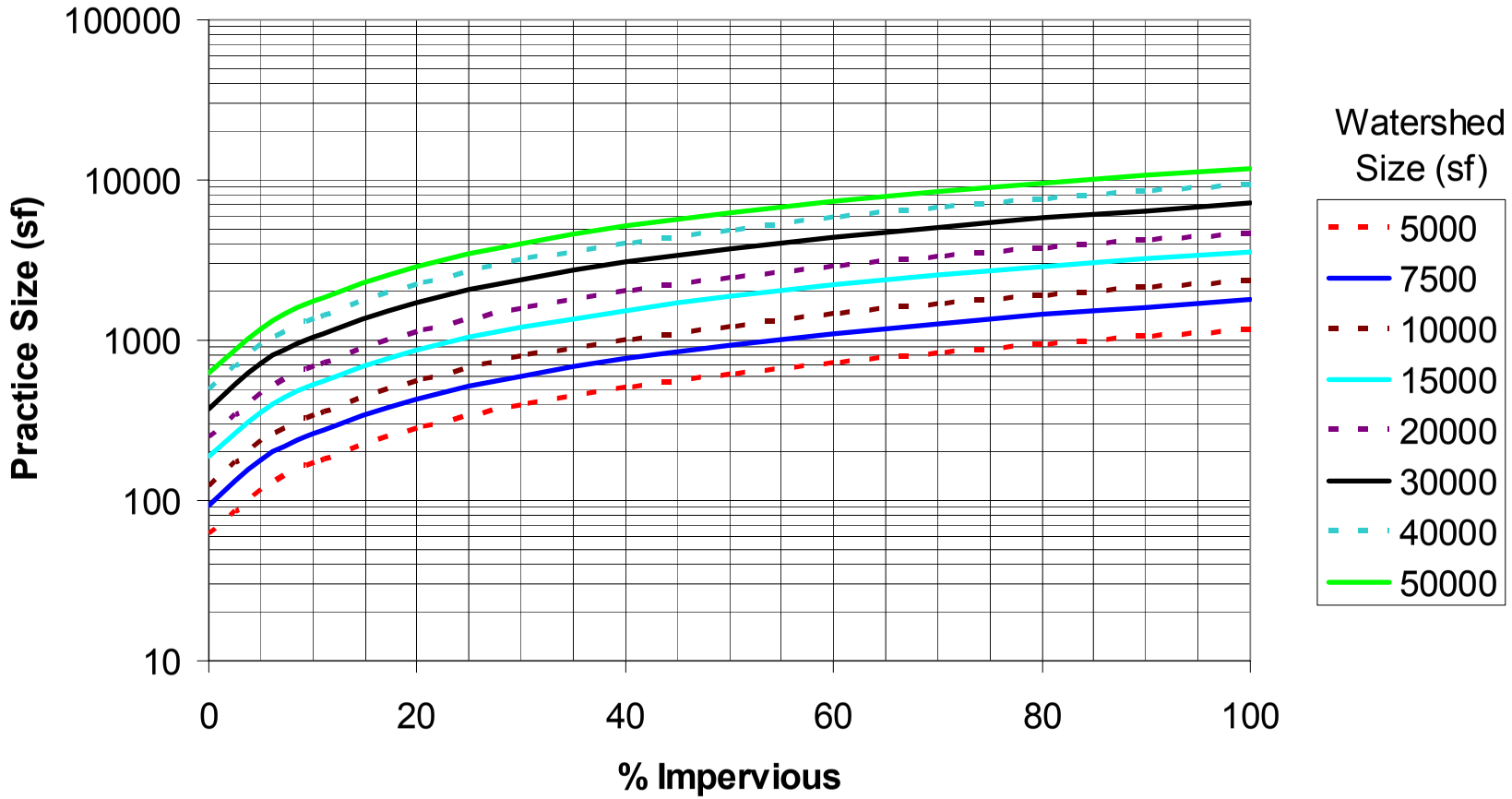


Figure D9: Wetland Surface Area as a function of Watershed Size (<5000 sf) and Impervious % (1" Rainfall) 3" ponding depth

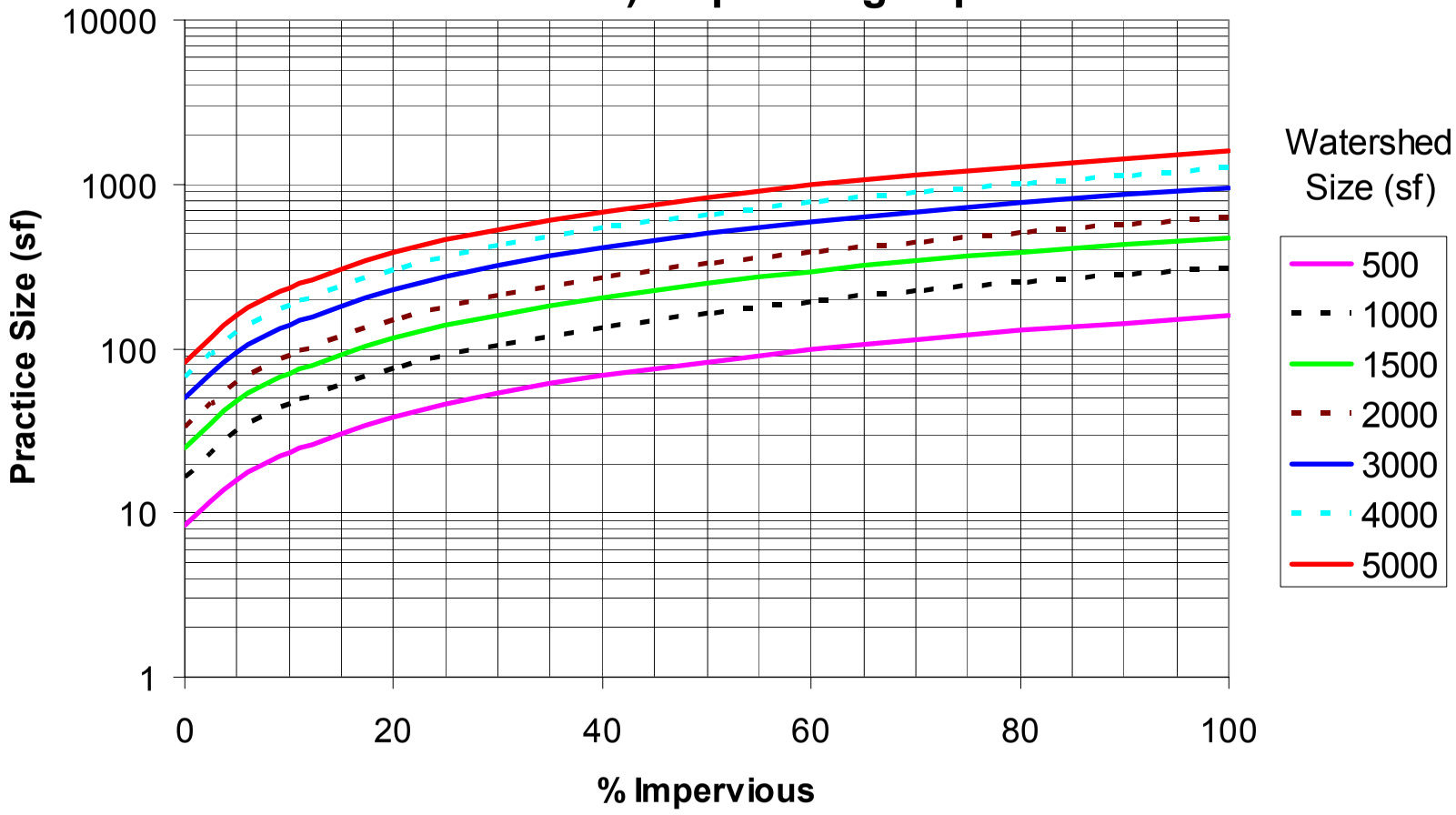


Figure D10: Wetland Surface Area as a function of Watershed Size (>5000 sf) and Impervious % (1" Rainfall) 3" ponding depth

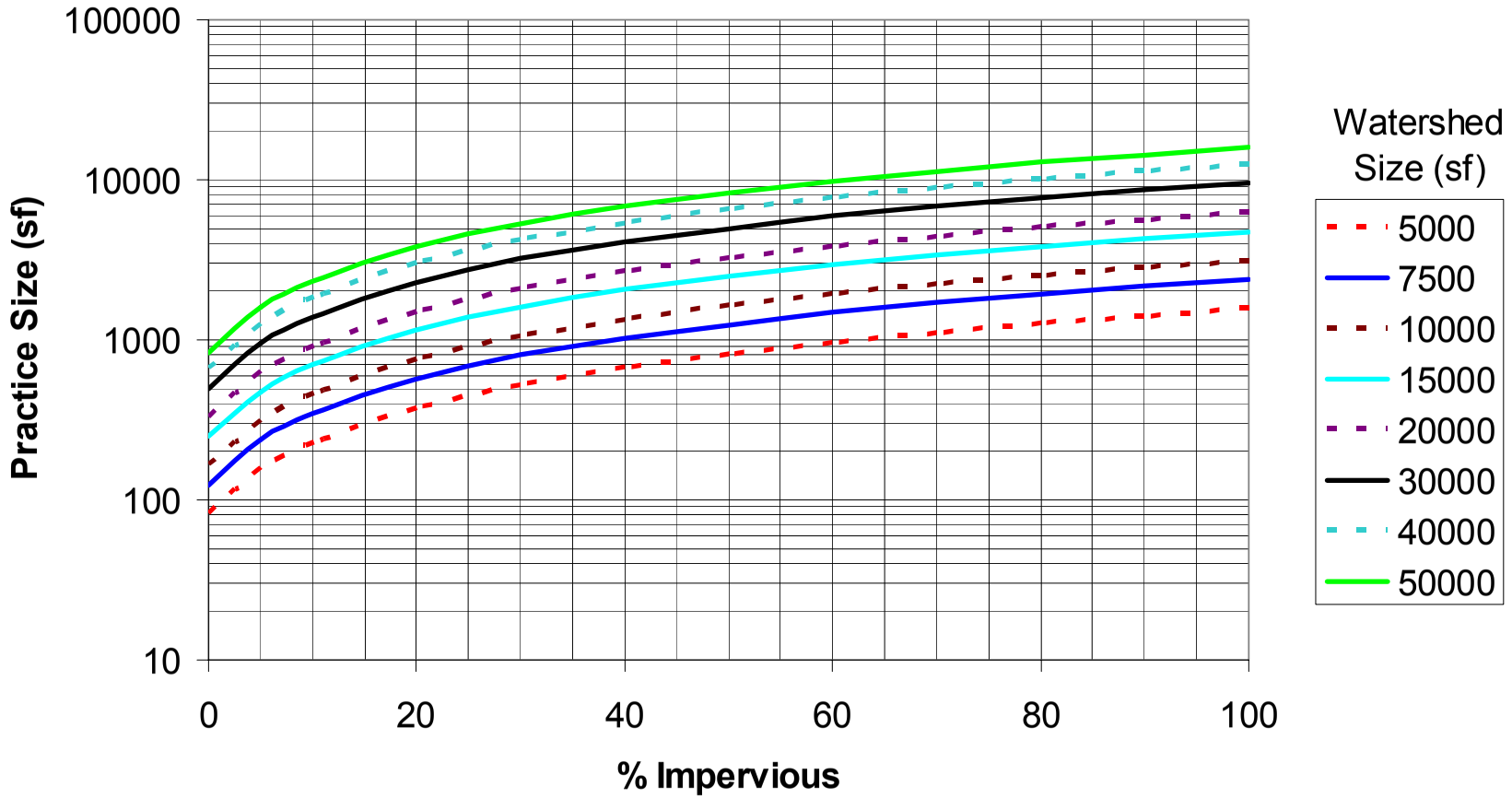


Figure D11: Wetland Surface Area as a function of Watershed Size (<5000 sf) and Impervious % (1.5" Rainfall) 3" ponding depth

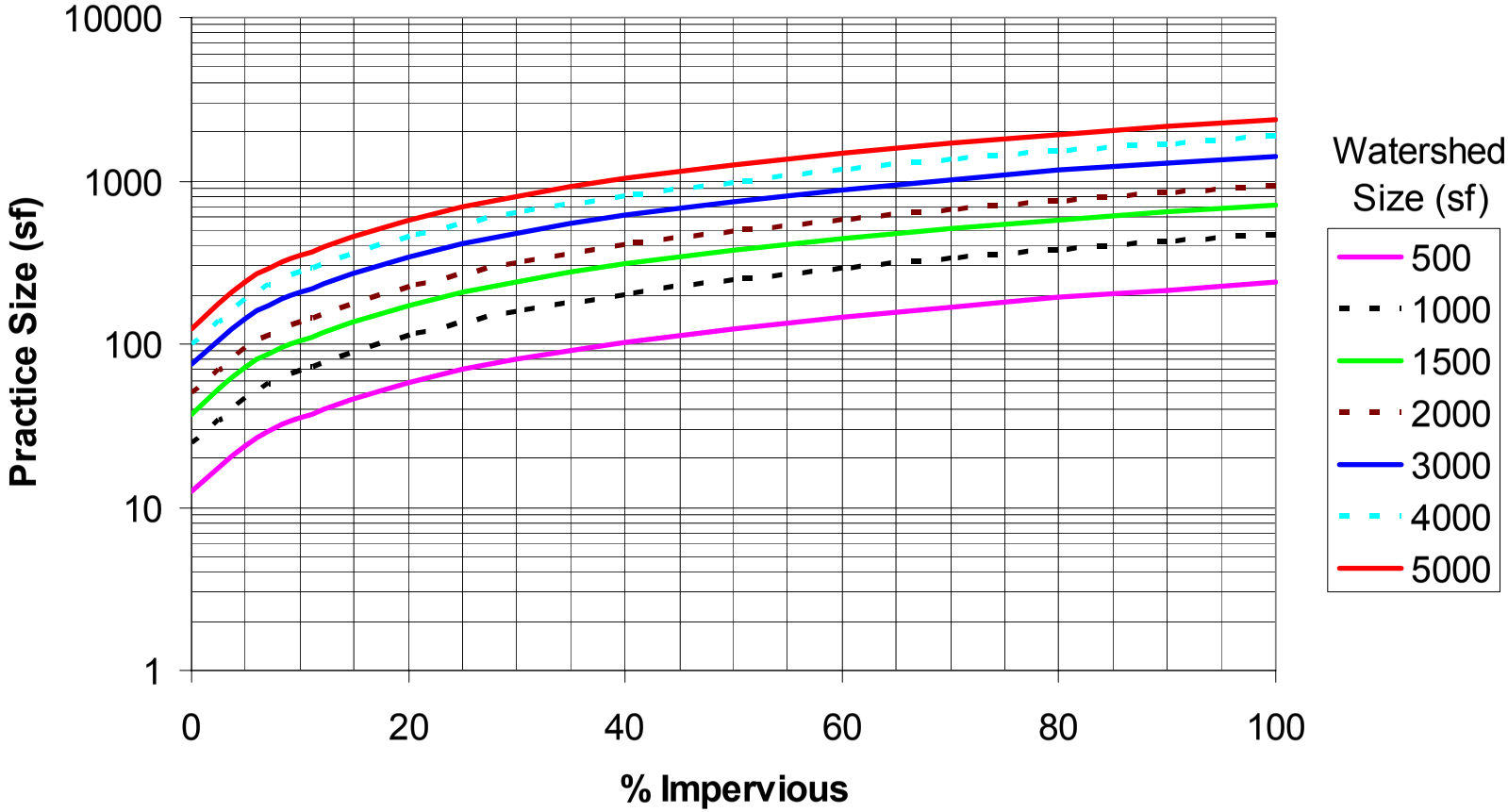
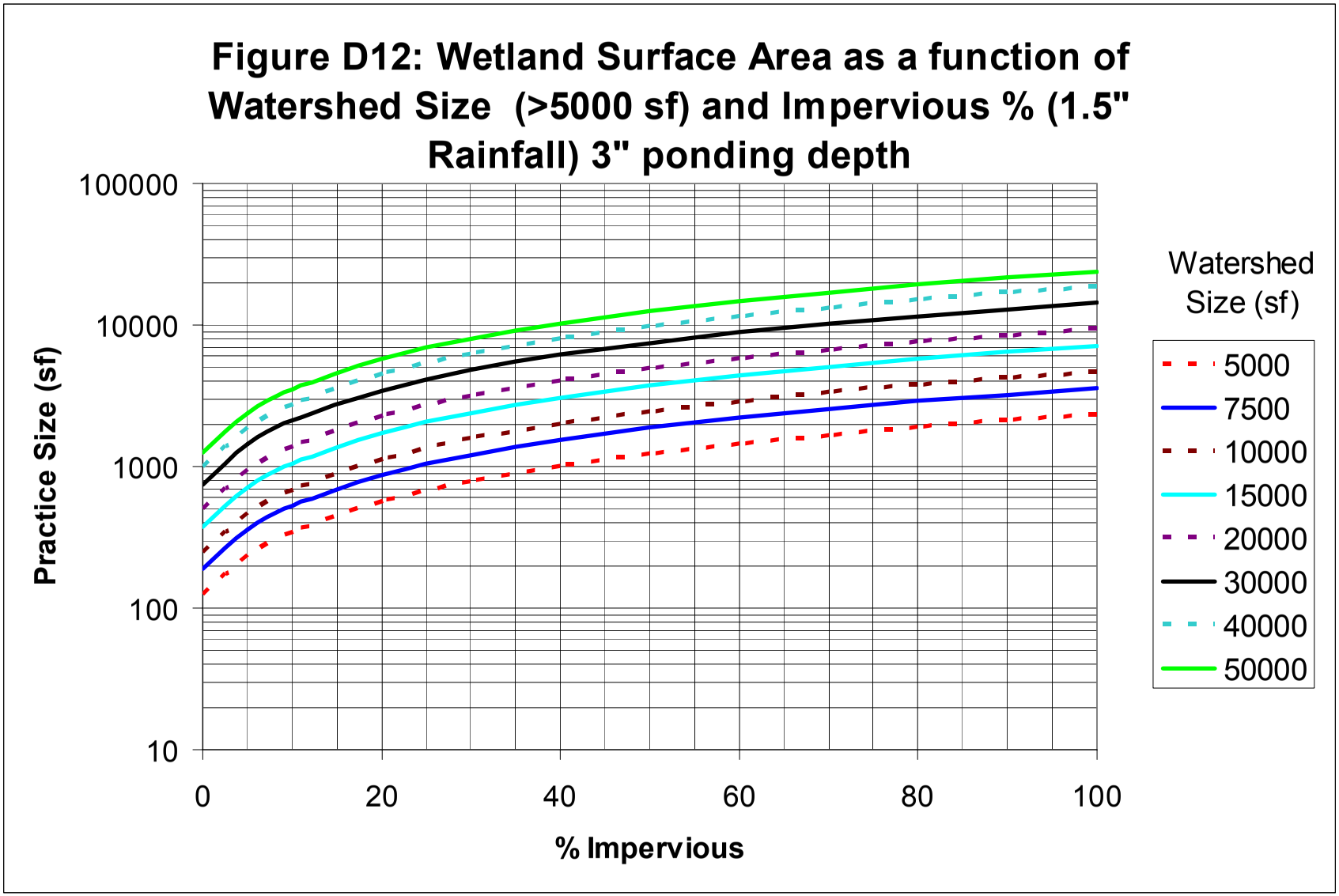


Figure D12: Wetland Surface Area as a function of Watershed Size (>5000 sf) and Impervious % (1.5" Rainfall) 3" ponding depth



APPENDIX E

Plant Selection for Normal Rain Gardens

Plants for Rain Gardens

Recommended for Southeastern North Carolina

Charlotte Glen, Urban Horticulture Agent,
North Carolina Cooperative Extension – New Hanover County Center

Soil conditions in rain gardens alternate between wet and dry, making them tough places for many plants to grow. The following plants are adapted to these conditions, though some plants will tolerate more moisture than others. Each plant is marked according to its flooding tolerance, with **3**'s being tolerant of longer flooding, **2**'s only tolerating brief flooding, and **1**'s indicate plants that tolerant extended drought once established.

All of these plants are native to the southeastern United States in wetland habitats and most are readily available at local nurseries. Wetland plants can generally grow well in moist or well-drained soils, whereas plants adapted to dry soils rarely survive in soggy conditions. How wet a rain garden stays will vary considerably depending on the site where it is installed. Rain gardens created on sandy soils will rarely hold water for more than a few hours. On these sites it is most important to choose plants for their drought tolerance. Rain gardens created on loamy or silty soils could pond water for 1-2 days (if your site ponds water for more than 3 days, you should consider creating a wetland). On these sites, choosing plants tolerant of extended flooding is critical to success.

Remember you are not limited to planting just within the excavated area! Extending plantings around this area will help the rain garden to blend in with the overall landscape. Any plants adapted to the site conditions can be used outside of the excavated area.

For more information on designing rain gardens and bioretention areas, refer to the following NCSU publication: Designing Rain Gardens (Bioretention Areas), available from your local NC Cooperative Extension office or online at: http://legacy.ncsu.edu/classes-a/bae/cont_ed/bioretention/lecture/design_rain.pdf

Large Trees (over 30' tall)

Deciduous

Red Maple (2) – *Acer rubrum*
River Birch (1,3) – *Betula nigra*
Green Ash (3) – *Fraxinux pennsylvanica*
Black Gum (2) – *Nyssa sylvatica*
Willow Oak (1,2) – *Quercus phellos*
Willows (3) – *Salix* species
Bald Cypress (1,3) – *Taxodium distichum*
Pond Cypress (1,3) - *Taxodium ascendens*
Nutall Oak (1,2) – *Quercus nuttalii*

Evergreen

Atlantic White Cedar (1,3) – *Chamaecyparis thyoides*
Southern Magnolia (1,2) – *Magnolia grandiflora*
Longleaf Pine (1,2) – *Pinus palustris*
Swamp Laurel Oak (3) – *Quercus laurifolia*

Small Trees (under 30' tall)

Deciduous

Red Buckeye (2) – *Aesculus pavia*
Ironwood (1,3) – *Carpinus caroliniana*
Redbud (1,2) – *Cercis canadensis*
Fringe Tree (2) – *Chionanthus virginicus*
Washington Hawthorn (3) – *Crataegus phaenopyrum*
Possumhaw (1,3) - *Ilex decidua*

Evergreen

Dahoon Holly (1,2) – *Ilex cassine*
American Holly (1,2) – *Ilex opaca*
Red Cedar (1,2) – *Juniperus virginiana*
Sweet Bay (3) – *Magnolia virginiana*
Devilwood (1,2) – *Osmanthus americanus*
Red Bay (1,2) – *Persea borbonia*

Evergreen shrubs that can be grown as small trees include Yaupon, Wax Myrtle, and Anise Shrub.

Shrubs

Deciduous

Chokeberry (1,3) – *Aronia arbutifolia*
Beautyberry (2) – *Callicarpa americana*
Sweet Shrub (2) – *Calycanthus floridus*
Buttonbush (3) – *Cephalanthus occidentalis*
Pepperbush (2) – *Clethra alnifolia*
Strawberry Bush (2) – *Euonymous americanus*
Fothergilla (2) – *Fothergilla gardenii*
Winterberry (3) – *Ilex verticillata*
Virginia Willow (3) – *Itea virginica*
Spicebush (2) – *Lindera benzion*
Possumhaw (3) – *Viburnum nudum*
Dusty Zenobia (2) – *Zenobia pulverulenta*

Shrubs continued. . . .

Evergreen

Florida Leucothoe (2) – *Agarista populifolia*
Inkberry (2) – *Ilex glabra*
Yaupon (1,2) – *Ilex vomitoria*
Florida Anise Shrub (3) – *Illicium floridanum*
Anise Shrub (1,2) – *Illicium parviflorum*
Coastal Leucothoe (2) – *Leucothoe axillaris*
Wax Myrtle (1,2) – *Myrica cerifera*
Dwarf Palmetto (3) – *Sabal minor*

Perennials

Blue Star (3) – *Amsonia tabernaemontana*
Lady Fern (2) – *Athyrium felix-femina*
Butterflyweed (1) – *Asclepias tuberosa*
Swamp Milkweed (3) – *Asclepias incarnata*
Climbing Aster (3) – *Aster carolinianus*
False Indigo (1,2) – *Baptisia species*
Boltonia (3) – *Boltonia asteriodes*
Turtlehead (3) – *Chelone glabra*
Green and Gold (2) – *Chrysongonum virginianum*
Mouse Ear Coreopsis (2) – *Coreopsis auriculata*
Tickseed (1,2) – *Coreopsis lanceolata*
Swamp Coreopsis (2) – *Coreopsis rosea*
Joe Pye Weed (3) – *Eupatorium dubium*
Swamp Sunflower (3) – *Helianthus angustifolius*
Swamp Mallow (3) – *Hibiscus moscheutos*
Texas Star (3) – *Hibiscus coccineus*
Blue Flag Iris (3) – *Iris virginica*
Seashore Mallow (3) – *Kosteletskya virginica*
Gayfeather (2) – *Liatris spicata*
Cardinal Flower (3) – *Lobelia cardinalis*
Cinnamon Fern (3) – *Osmunda cinnamomea*
Royal Fern (3) – *Osmunda regalis*
Garden Phlox (2) – *Phlox paniculata*
Moss Pinks (1,2) – *Phlox subulata*
Rudbeckia (1,2) – *Rudbeckia fulgida*
Green Headed Coneflower (3) – *Rudbeckia laciniata*
Goldenrod (3) – *Solidago rugosa*
Stoke's Aster (2) – *Stokesia laevis*
Ironweed (3) – *Vernonia novaboracensis*
Verbena (1,2) – *Verbena canadensis*

Ornamental Grasses

River Oats (1,3) – *Chasmanthium latifolium*
Muhly Grass (1,2) – *Muhlenbergia capillaris*
Panic Grass (1,3) – *Panicum virgatum*
Indiangrass (1,2) – *Sorghastrum nutans*

Sedges and Rushes

Lurid Sedge (3) – *Carex lurida*
Fringed Sedge (3) – *Carex crinita*
Southern Waxy Sedge (3) – *Carex glaucescens*
White-topped Sedge (3) – *Rhynchospora latifolia*
Woolgrass (3) - *Scirpus cyperinus*

Non-native perennials and ornamental grasses suitable for rain gardens include: Liriope (1,2) (*Liriope muscarii* and *L. spicata*), Siberian Iris (2) (*Iris sibirica*), Daylily (1,2) (*Hemerocallis* hybrids), Rain Lilies (3) (*Zephyranthes* species), Crinum Lilies (3) (*Crinum* species), Japanese Painted Fern (2) (*Athyrium nipponicum*) and Maiden Grass (1,2) (*Miscanthus* cultivars).

1 **Plants that, once established*, can withstand considerable drought (3-4 weeks without rainfall)**

2 **Plants that grow best in moist to average soils and will only tolerate short periods (1-2 days) of flooding.**

3 **Plants that will tolerate longer periods of flooding (3-5 days), but will also grow in moist to average soils.**

*Establishment usually takes 1-2 years for trees and shrubs and 1 year for perennials.

For more detailed information and images of each plant, visit the Plant Fact Sheets available on NCSU's Urban Horticulture website:
www.ncstate-plants.net

NC STATE UNIVERSITY
A&T STATE UNIVERSITY
COOPERATIVE EXTENSION
Helping People Put Knowledge to Work

Plants for Rain Gardens

Recommended for central North Carolina

Charlotte Glen, Urban Horticulture Agent,
North Carolina Cooperative Extension – New Hanover County Center

Soil conditions in rain gardens alternate between wet and dry, making them tough places for many plants to grow. The following plants are adapted to these conditions, though some plants will tolerate more moisture than others. Each plant is marked according to its flooding tolerance, with **3**'s being tolerant of longer flooding, **2**'s only tolerating brief flooding, and **1**'s indicate plants that tolerant extended drought once established.

All of these plants are native to the southeastern United States in wetland habitats and most are readily available at local nurseries. Wetland plants can generally grow well in moist or well-drained soils, whereas plants adapted to dry soils rarely survive in soggy conditions. How wet a rain garden stays will vary considerably depending on the site where it is installed. Rain gardens created on sandy soils will rarely hold water for more than a few hours. On these sites it is most important to choose plants for their drought tolerance. Rain gardens created on loamy or silty soils could pond water for 1-2 days (if your site ponds water for more than 3 days, you should consider creating a wetland). On these sites, choosing plants tolerant of extended flooding is critical to success.

Remember you are not limited to planting just within the excavated area! Extending plantings around this area will help the rain garden to blend in with the overall landscape. Any plants adapted to the site conditions can be used outside of the excavated area.

Large Trees (over 30' tall)

Deciduous

Red Maple (2) – *Acer rubrum*
River Birch (1,3) – *Betula nigra*
Green Ash (3) – *Fraxinux pennsylvanica*
Black Gum (2) – *Nyssa sylvatica*
Willow Oak (1,2) – *Quercus phellos*
Willows (3) – *Salix* species
Nutall Oak (1,2) – *Quercus nuttalii*

Evergreen

Southern Magnolia (1,2) – *Magnolia grandiflora*
Swamp Laurel Oak (3) – *Quercus laurifolia*

Small Trees (under 30' tall)

Deciduous

Red Buckeye (2) – *Aesculus pavia*
Ironwood (1,3) – *Carpinus caroliniana*
Redbud (1,2) – *Cercis canadensis*
Fringe Tree (2) – *Chionanthus virginicus*
Washington Hawthorn (3) – *Crataegus phaenopyrum*
Possumhaw (1,3) - *Ilex decidua*

Evergreen

American Holly (1,2) – *Ilex opaca*
Red Cedar (1,2) – *Juniperus virginiana*

Shrubs

Deciduous

Chokeberry (1,3) – *Aronia arbutifolia*
Beautyberry (2) – *Callicarpa americana*
Sweet Shrub (2) – *Calycanthus floridus*
Buttonbush (3) – *Cephalanthus occidentalis*
Pepperbush (2) – *Clethra alnifolia*
Strawberry Bush (2) – *Euonymous americanus*
Winterberry (3) – *Ilex verticillata*
Virginia Willow (3) – *Itea virginica*
Spicebush (2) – *Lindera benzion*
Possumhaw (3) – *Viburnum nudum*

Evergreen

Inkberry (2) – *Ilex glabra*
Wax Myrtle (1,2) – *Myrica cerifera*

Perennials

Blue Star (3) – *Amsonia tabernaemontana*
Lady Fern (2) – *Athyrium felix-femina*
Butterflyweed (1) – *Asclepias tuberosa*
Swamp Milkweed (3) – *Asclepias incarnata*
Climbing Aster (3) – *Aster carolinianus*
False Indigo (1,2) – *Baptisia species*
Boltonia (3) – *Boltonia asteriodes*
Turtlehead (3) – *Chelone glabra*
Green and Gold (2) – *Chrysogonum virginianum*
Mouse Ear Coreopsis (2) – *Coreopsis auriculata*
Tickseed (1,2) – *Coreopsis lanceolata*
Swamp Coreopsis (2) – *Coreopsis rosea*
Joe Pye Weed (3) – *Eupatorium dubium*
Swamp Sunflower (3) – *Helianthus angustifolius*
Swamp Mallow (3) – *Hibiscus moscheutos*
Texas Star (3) – *Hibiscus coccineus*
Blue Flag Iris (3) – *Iris virginica*
Cardinal Flower (3) – *Lobelia cardinalis*
Cinnamon Fern (3) – *Osmunda cinnamomea*

Royal Fern (3) – *Osmunda regalis*
Garden Phlox (2) – *Phlox paniculata*
Moss Pinks (1,2) – *Phlox subulata*
Rudbeckia (1,2) – *Rudbeckia fulgida*
Green Headed Coneflower (3) – *Rudbeckia laciniata*
Goldenrod (3) – *Solidago rugosa*
Ironweed (3) – *Vernonia novaboracensis*

Ornamental Grasses

River Oats (1,3) – *Chasmanthium latifolium*
Muhly Grass (1,2) – *Muhlenbergia capillaris*
Panic Grass (1,3) – *Panicum virgatum*
Indiangrass (1,2) – *Sorghastrum nutans*

Sedges and Rushes

Lurid Sedge (3) – *Carex lurida*
Fringed Sedge (3) – *Carex crinita*
White-topped Sedge (3) – *Rhynchospora latifolia*
Woolgrass (3) - *Scirpus cyperinus*

Non-native perennials and ornamental grasses suitable for rain gardens include: Liriope (1,2) (*Liriope muscarii* and *L. spicata*), Siberian Iris (2) (*Iris sibirica*), Daylily (1,2) (*Hemerocallis* hybrids), Rain Lilies (3) (*Zephyranthes* species), Crinum Lilies (3) (*Crinum* species), Japanese Painted Fern (2) (*Athyrium nipponicum*) and Maiden Grass (1,2) (*Miscanthus* cultivars).

1 **Plants that, once established*, can withstand considerable drought (3-4 weeks without rainfall)**

2 **Plants that grow best in moist to average soils and will only tolerate short periods (1-2 days) of flooding.**

3 **Plants that will tolerate longer periods of flooding (3-5 days), but will also grow in moist to average soils.**

*Establishment usually takes 1-2 years for trees and shrubs and 1 year for perennials.

NC STATE UNIVERSITY A&T STATE UNIVERSITY COOPERATIVE EXTENSION
Helping People Put Knowledge to Work

*For more detailed information and images of each plant, visit the Plant Fact Sheets available on NCSU's Urban Horticulture website: **www.ncstate-plants.net***

Plants for Rain Gardens

Recommended for Western North Carolina

Charlotte Glen, Urban Horticulture Agent,
North Carolina Cooperative Extension – New Hanover County Center

Soil conditions in rain gardens alternate between wet and dry, making them tough places for many plants to grow. The following plants are adapted to these conditions, though some plants will tolerate more moisture than others. Each plant is marked according to its flooding tolerance, with **3**'s being tolerant of longer flooding, **2**'s only tolerating brief flooding, and **1**'s indicate plants that tolerant extended drought once established.

All of these plants are native to the southeastern United States in wetland habitats and most are readily available at local nurseries. Wetland plants can generally grow well in moist or well-drained soils, whereas plants adapted to dry soils rarely survive in soggy conditions. How wet a rain garden stays will vary considerably depending on the site where it is installed. Rain gardens created on sandy soils will rarely hold water for more than a few hours. On these sites it is most important to choose plants for their drought tolerance. Rain gardens created on loamy or silty soils could pond water for 1-2 days (if your site ponds water for more than 3 days, you should consider creating a wetland). On these sites, choosing plants tolerant of extended flooding is critical to success.

Remember you are not limited to planting just within the excavated area! Extending plantings around this area will help the rain garden to blend in with the overall landscape. Any plants adapted to the site conditions can be used outside of the excavated area.

For more information on designing rain gardens and bioretention areas, refer to the following NCSU publication: Designing Rain Gardens (Bioretention Areas), available from your local NC Cooperative Extension office or online at: http://legacy.ncsu.edu/classes-a/bae/cont_ed/bioretention/lecture/design_rain.pdf

Large Trees (over 30’ tall)

Deciduous

Red Maple (2) – *Acer rubrum*
River Birch (1,3) – *Betula nigra*
Cherry birch (2) – *Betula lenta*
Willows (3) – *Salix* species
Bald cypress (1,3) – *Taxodium distichum*
Sycamore (2) – *Platanus occidentalis*
Yellow buckeye (2) – *Aesculus octandra*
Persimmon (2) – *Diospyros virginiana*
Silverbell (1) – *Halesia carolina*
Blackgum (3) – *Nyssa sylvatica*
Black cherry (2) – *Prunus serotina*
White basswood (1) – *Tilia heterophylla*
Box Elder (3) – *Acer negundo*

Evergreen

-

Small Trees (under 30’ tall)

Deciduous

Ironwood (1,3) – *Carpinus caroliniana*
Redbud (1,2) – *Cercis canadensis*
Fringe Tree (2) – *Chionanthus virginicus*
Washington Hawthorn (3) – *Crataegus phaenopyrum*
Umbrella Tree (2) – *Magnolia tripetala*
PawPaw (2) – *Asimina triloba*
Tag Alder (3) – *Alnus serrulata*
Serviceberry (2) – *Amelanchier arborea*
Pagoda Dogwood (1) – *Cornus alternifolia*
Witch-hazel (1) – *Hamamelis virginiana*
Silky Dogwood (3) –*Cornus amomum*

Evergreen

American Holly (1,2) – *Ilex opaca*
Sweetbay Magnolia (3) – *Magnolia virginiana*

Shrubs

Deciduous

Chokeberry (1,3) – *Aronia arbutifolia*
Sweet Shrub (2) – *Calycanthus floridus*
Buttonbush (3) – *Cephalanthus occidentalis*
American Hazelnut (1) – *Corylus americana*
Strawberry Bush (2) – *Euonymous americanus*
Winterberry (3) – *Ilex verticillata*
Virginia Sweetspire (3) – *Itea virginica*
Spicebush (2) – *Lindera benzion*
Ninebark (2) – *Physocarpus opulifolius*
Common Elderberry (2) – *Sambucus canadensis*
Meadowsweet (3) – *Spiraea latifolia*
Hardhack (3) – *Spiraea tomentosa*
Swamp Azalea (3) – *Rhododendron viscosum*
Swamp Rose (3) – *Rosa palustris*
Blueberry (1) – *Vaccinium ashei*
Arrow-wood (2) – *Viburnum dentatum*
Possumhaw (3) – *Viburnum nudum*

Evergreen

Native Brake-Cane (3) – *Arundinaria gigantea*
Carolina Rose (1) – *Rosa carolina*

Perennials

Blue Star (3) – *Amsonia tabernaemontana*
Lady Fern (2) – *Athyrium felix-femina*
Swamp Milkweed (3) – *Asclepias incarnata*
Butterflyweed (1) – *Asclepias tuberosa*
False Indigo (1,2) – *Baptisia species*
Turtlehead (3) – *Chelone glabra*
Green and Gold (2) – *Chrysongonum virginianum*
Mouse Ear Coreopsis or Lobed Tickseed (2) – *Coreopsis auriculata*
Lanceleaf Tickseed (1,2) – *Coreopsis lanceolata*
Rose Mallow (3) – *Hibiscus moscheutos*
Texas Star (3) – *Hibiscus coccineus*
Jewelweed (3) –*Impatiens capensis*
Swamp Iris (3) –*Iris versicolor*
Blue Flag Iris (3) – *Iris virginica*
Gayfeather (2) – *Liatris spicata*
Cardinal Flower (3) – *Lobelia cardinalis*
Cinnamon Fern (3) – *Osmunda cinnamomea*
Royal Fern (3) – *Osmunda regalis*
Garden Phlox (2) – *Phlox paniculata*
Moss Pinks (1,2) – *Phlox subulata*
Pickerelweed (3) –*Pontedara cordata*
Rudbeckia (1,2) – *Rudbeckia fulgida*
Cutleaf Coneflower (3) – *Rudbeckia laciniata*
Goldenrod (3) – *Solidago rugosa*
Stoke's Aster (2) – *Stokesia laevis*

Ironweed (3) – *Vernonia novaboracensis*

Ornamental Grasses

River Oats (1,3) – *Chasmanthium latifolium*
Panic Grass (1,3) – *Panicum virgatum*
Indiangrass (1,2) – *Sorghastrum nutans*

Sedges and Rushes

Lurid Sedge (3) – *Carex lurida*
Fringed Sedge (3) – *Carex crinita*
Woolgrass (3) - *Scirpus cyperinus*
Soft Rush (3) –*Juncus effuses*

1 **Plants that, once established*, can withstand considerable drought (3-4 weeks without rainfall)**

2 **Plants that grow best in moist to average soils and will only tolerate short periods (1-2 days) of flooding.**

3 **Plants that will tolerate longer periods of flooding (3-5 days), but will also grow in moist to average soils.**

*Establishment usually takes 1-2 years for trees and shrubs and 1 year for perennials.

For more detailed information and images of each plant, visit the Plant Fact Sheets available on NCSU's Urban Horticulture website:
www.ncstate-plants.net

NC STATE UNIVERSITY
A&T STATE UNIVERSITY
COOPERATIVE EXTENSION
Helping People Put Knowledge to Work

APPENDIX F

Plant Selection for Zone Rain Garden

List of adaptable plants that can be used in a zoned rain garden.

Large Trees

River Birch - Betula nigra
Bald Cypress - Taxodium distichum

Small Trees, 10'-20'

Green Hawthorn - Crataegus viridus
Possumhaw - Ilex decidua
Sweet Bay - Magnolia virginiana

Shrubs

Buttonbush - Cephalanthus occidentalis (not as readily available others but very tough)
Virginia Willow - Itea virginica
Possumhaw - Viburnum nudum
Winterberry - Ilex verticillata
Dwarf Palmetto - */Sabal minor/* (Coastal Plains Only)

Perennials

Blue Star - Amsonia tabernaemontana
Joe Pye Weed - Eupatorium dubium
Blue Flag Iris - Iris virginica
Ironweed - Vernonia novaboracensis
Swamp Mallow - Hibiscus moscheutos
Common Rush - Juncus effusus

APPENDIX G

Pond and Wetland Maintenance

URBAN Waterways

Maintenance of Stormwater Wetlands and Wet Ponds

Stormwater management practices must be kept in proper working order to maintain their intended functions and aesthetic appeal.

This publication presents maintenance guidelines for stormwater wetlands and wet ponds, two stormwater practices that are being constructed across North Carolina.

OVERVIEW

As its name implies, a *stormwater wetland* is a wetland system designed to treat stormwater runoff. Wetlands typically have shallow water (except for intermittent deep pools) and dense vegetation. A well-functioning stormwater wetland will be a diverse ecosystem that includes many plant and animal species. It will also do an excellent job of removing pollution from stormwater runoff—its intended function. Stormwater wetlands are very efficient at nutrient removal. Recent studies conducted by North Carolina State University researchers indicate that a stormwater wetland removes 40 to 80 percent of all nitrogen and 50 to 70 percent of all phosphorus entering the wetland. Figure 1 depicts some wetlands located across North Carolina. (For more information on stormwater wetlands, see *Designing Stormwater Wetlands for Small Watersheds*, AG-588-02, in the Urban Waterways fact sheet series.)

Wet ponds are typically much deeper than stormwater wetlands—their average depth ranges from 4 to 8 feet. They are designed so that most of the pond is open water. Wet ponds are the most common stormwater management practice in North Carolina and have been constructed since the 1970s in some parts of the state. More recent pond configurations incorporate wetland features, such as an aquatic shelf (or wetland bench) and a forebay.

An *aquatic shelf* is a shallow-water zone of a pond, usually along the bank edges, planted with wetland vegetation. These shelves flood during storms. A *forebay* is a pool where inflow first enters the pond, and heavier pollutants, such as sediment, initially settle there. Research conducted across the United States shows that wet ponds effectively remove sediment and the pollutants associated with it from stormwater. Both wet ponds and stormwater wetlands can

Distributed in furtherance of the acts of Congress of May 8 and June 30, 1914. North Carolina State University and North Carolina A&T State University commit themselves to positive action to secure equal opportunity regardless of race, color, creed, national origin, religion, sex, age, or disability. In addition, the two Universities welcome all persons without regard to sexual orientation. North Carolina State University, North Carolina A&T State University, U.S. Department of Agriculture, and local governments cooperating.

NC STATE UNIVERSITY A&T STATE UNIVERSITY COOPERATIVE EXTENSION
Helping People Put Knowledge to Work

Figure 1. Stormwater wetlands across North Carolina: (A) Brevard College in the mountains; (B) Hillandale Golf Course in Durham; (C) Carteret-Craven Electric Cooperative near Morehead City; and (D) Smithfield-Selma Senior High School in Johnston County.

be used for flood control as well. For more information on stormwater practices, see *Urban Stormwater Structural Best Management Practices (BMPs)* in the Urban Waterways series (AG-588-01).

MAINTENANCE GOALS

Maintenance of stormwater wetlands and wet ponds is performed to achieve four goals: efficient hydraulic flow and pollutant removal, aesthetic appeal, safety, and mosquito control. Most of the maintenance activities associated with wetlands and wet ponds pertain to two or more of these goals. The following activities should be performed regularly to maintain stormwater wetland and wet pond efficiency:

- Remove sediment and gross solids from forebays.
- Keep the orifice (the drawdown hole) free-flowing.
- Clean away floating trash and debris.
- Remove vegetation along the dam face.
- Remove invasive plant species.
- Mow the perimeter of wet ponds.
- Control pests, such as muskrats and beavers.

REMOVE SEDIMENT AND GROSS SOLIDS FROM FOREBAYS

Forebays are located at the inlets to stormwater wetlands and wet ponds. They are designed to slow incoming water, dissipating the water's energy, and to provide a location for sediment and other gross solids (such as leaves, other tree debris, cigarette butts, and trash) to settle and accumulate.

A forebay is typically 2 feet deep in a stormwater wetland and sometimes deeper in a wet pond. If the forebay fills with sediment and gross solids, these materials will bypass the forebay and begin to accumulate in other portions of the wetland or wet pond that may be more ecologically sensitive.

To check sediment levels inside the forebay, record the depth of the forebay at the same time each year. Depending on the size of the forebay, a fish finder can be used from a small boat or someone can survey the depth along a grid of the forebay with a rod (Figure 2). If the forebay water is clear, the depth can often be determined visually.

Once the forebay is half full of sediment or the average sediment level is within 1 foot of the water

Figure 2. Inspection (A) of sediment depth and cleaning or "dipping" (B) of forebays. A long boom on the excavator is sometimes essential to access sediment collected in the middle of the forebay.

surface, remove the sediment and gross solids. This task is typically accomplished by a track hoe or backhoe (Figure 2). The water level inside the wet pond or stormwater wetland can be lowered, if needed, to aid excavation of the forebay. Depending upon the size of the forebay, cleaning it can require anywhere from a day to a week.

Once the excavated soil (or *spoils*) from the dredging has begun to dry, either spread it in the watershed away from the banks of the wetland or wet pond and seed it, or take it to a landfill. Consider the location when disposing of the soil. Spoils from wet ponds downstream of industrial facilities may contain pollutants that need to be disposed of in a landfill, while those from a residential wetland or wet pond may not. If there is any concern as to proper disposal, samples of the excavated soil should be sent to a laboratory for chemical analysis. This can be costly.

A recent study by N.C. State researchers indicates that sediment and gross solids from forebays typically need to be removed (also known as *dipped* or *dredged*) once every 5 to 10 years. If wet ponds and stormwater wetlands are located in watersheds with active construction, however, spoils may need to be removed as often as once a year.

Like the forebay, the final *deep pool* of the pond or wetland near the outlet also must be inspected and maintained. The major difference between the two is that the final deep pool takes longer to fill with soil. The drawdown hole (located at the outlet and described in the next section) is where captured stormwater slowly drains from the wetland or wet pond. It must be free of accumulated debris and sediment to work properly. Remove sediment and gross solids from the deep pool near the outlet whenever the material is within 1 vertical foot of the drawdown hole.

What Designers Can Do To Make Forebay Cleanout Easier

Access to older wet ponds and stormwater wetlands is often a problem. New design recommendations can make forebay cleanout easier by improving accessibility:

- Include reinforced paths that give heavy equipment easy access to the forebay (Figure 3). Sometimes the path doubles as a separation between the forebay and the remainder of the pond.
- Make forebays relatively long and narrow. A narrow forebay makes it easier for a trackhoe or backhoe arm to reach at least to the middle of the forebay from either side.

Figure 3. A wide path is provided for heavy equipment to access the forebay (located to the right of the path).

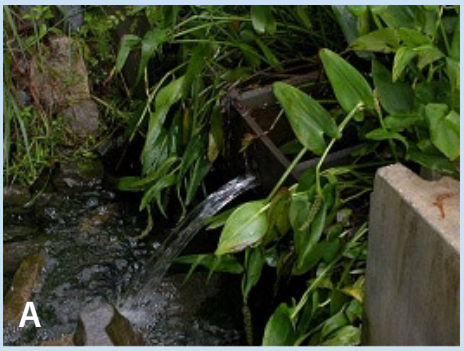


Figure 4. A small orifice allows slow release of captured stormwater (A), but can easily clog due to its size. A clogged orifice can affect plant communities inside the wetland or wet pond (B).

KEEP THE ORIFICE (DRAWDOWN HOLE) FREE FLOWING

Wetlands and wet ponds are designed to capture and detain stormwater from 2 to 5 days. On smaller ponds and wetlands, a relatively small hole or *orifice* is used to detain water for this period. The diameter of the orifice can be as small as 2 inches, which makes it susceptible to clogging (Figure 4). Because many ponds and all wetlands contain vegetation, dead plants can float to and clog the orifice. Moreover, floating trash and debris (see the next section) will potentially clog the orifice.

A clogged drawdown hole poses several problems, including the loss of storage to capture later storms and flooding of desirable plant species. When water levels remain too deep for the desirable plants to survive, stronger, usually invasive, plant species take over. The aesthetics and performance of the practice can suffer when the plant community changes.

The wetland or wet pond needs to store water between storms to perform its intended function. It cannot store water from the next storm effectively if the orifice is clogged and the wetland is continually full.

Unclogging the orifice is relatively simple. Clean the hole with a stick, a piece of wire, a pole, or your hand. Inspect it regularly—the drawdown hole can clog at any time. Visit the site once a month to make sure water is flowing freely through the orifice, and inspect the outlet after every rainfall event exceeding 2 inches.

WHY SUCH A SMALL HOLE?

A large opening would release the water too quickly and not provide adequate time for treatment. Stormwater wetlands and wet ponds are designed to capture the first flush (or water quality volume) from their upstream drainage areas. The first flush is runoff generated by a 1 to 1.5 inch storm. The total volume of water can range up to several acre-feet. Once the first flush is captured in the wetland or wet pond, it must be slowly released to allow time for sediment and other gross solids to settle. Design standards require that the first-flush volume be kept for at least 2 days, with a recommended 3- to 4-day retention time. To release this water slowly, a small hole is often necessary. When the hole is only 2, 3, or 4 inches in diameter, clogging is a significant concern.

CLEAN AWAY FLOATING DEBRIS AND TRASH

Stormwater wetlands and wet ponds are located in low elevations of the landscape. All water from several acres drains to wetlands and wet ponds. With this water comes trash and other debris, called *floatage*. It must be removed from wetlands and wet ponds for several reasons:

- It is unsightly, particularly when the wetland or wet pond is designed to be an attractive amenity.
- Floating trash, such as cups or plastic bags, often store small amounts of water in a sheltered environment. Studies have shown that mosquito larvae are more likely to be protected inside floating trash than in the exposed pond.
- Trash and other floating debris can clog the drawdown hole (the orifice), which is often used to slowly release captured runoff (Figure 5).

Inspect wet ponds and wetlands for trash regularly and frequently—typically once a month but occasionally once a week. On smaller wetlands and wet ponds, collect trash by simply wading along the edges. With

Figure 5. Trash floats to the drawdown hole, where it can clog the small hole, restricting flow. Removing the trash is often very simple, but essential.

larger facilities, a small boat or vac truck may be required. Because most trash follows the movement of water, it tends to collect near the outlet of the wetland or wet pond. This makes trash easier to collect, but it increases the risk of clogging the drawdown orifice.

REMOVE VEGETATION ALONG THE DAM FACE

Dam inspection officials require earthen dams to be free of large shrubs and trees. Roots can conduct water through the dam from the open pond to the downstream side of the embankment. The movement of water along the roots is called *piping*, which can eventually lead to soil erosion and, if unchecked, dam failure. Piping tends to be a problem for large ponds and wetlands that have a large dam face. Some small wetlands and wet ponds and those with concrete dams do not have this problem. If a dam face is vegetated, it should be grassed exclusively.

Inspect the dam once a year, and remove all shrubs and trees from the dam top and both faces. If the wetland or wet pond has been regularly maintained and any shrubs and trees growing are juvenile, simply mowing the bank is sufficient. Otherwise, a weed wiper, which applies herbicides to plants more than 12 inches tall, can be used along the bank. The weed wiper will kill any plant it touches or scrapes.

If a bank is severely overgrown, trees and shrubs should be cut down and removed. A systemic herbicide can be applied to the freshly cut stumps, which will kill the root systems. This is a laborious process. If the dam face is heavily overgrown, a contractor who specializes in removal should be consulted. Because dams of larger ponds and wetlands are responsible for retaining large volumes of water, dam failure can be catastrophic if homes, businesses, or roads are downstream.

REMOVE INVASIVE PLANT SPECIES

Stormwater wetlands and wet ponds with aquatic shelves can become overgrown with invasive plants. The most common invasive plant is the cattail (*Typha* species, Figure 6). Cattails, while native to North Carolina, crowd out other, more desirable plants. Cattails tolerate a variety of conditions and do a good job of pollutant removal. From this functional standpoint, cattails can be considered good plants to have in a wetland. *However,* cattail monocultures fail to meet two very important design goals: aesthetics and mosquito control.

A wetland or wet pond that is overgrown with cattails is not a diverse ecosystem. Ecosystem diversity is critical for mosquito control. Cattails provide a safe environment for mosquito larvae to mature to adulthood. When cattails go dormant in the fall, some of the fronds will form a protective thicket for mosquitoes. For more information on mosquito control in wetlands and wet ponds, see *Mosquito Control for Stormwater Practice Designers and Managers* (AGW-588-04) in the Urban Waterways series.

Figure 6. (A) Cattails (*Typha* sp.) and (B) common reeds (*Phragmites* sp.) are very aggressive invasive species. Once established, each plant will crowd out more desirable plant species.

Figure 7. Aquatic glyphosate (herbicide) can be applied via direct contact (a protected hand) or via a small weed-wipe pole (A). Stroking individual cattail fronds sends the herbicide down the shoot and reaches tubers located in the soil (B). Once the herbicide reaches the tubers, the cattails will die within 2-3 days (C). The herbicide can also be applied with a small brush. *(Franklin County Cooperative Extension Center)*

Removing cattails can be challenging. It is almost impossible to remove a mass of cattails by hand. Cattails grow from tubers that spread, and they also spread by seed. If a piece of cattail is left in the wetland or wet pond after removal, the stand will probably re-establish. Use a backhoe for mass cattail removal when a wet pond or wetland is completely overgrown by cattails.

If a wetland or wet pond has a variety of vegetation but cattails are beginning to colonize it, use an alternative form of cattail removal, such as applying an aquatic formulation of the herbicide glyphosate (one trade name for this is Rodeo). Wear a chemical-resistant glove underneath a cloth glove. Soak the cloth glove in 2 percent glyphosate, and stroke the cattail leaves. Or brush the herbicide onto the leaves with a small weed wiper. Not every leaf needs to be touched by the herbicide because many of the cattails are connected by tubers. Within 10 to 12 days, the cattails fronds will wither and die (Figure 7).

The herbicide must be applied by hand rather than by broadcast spray because it will kill every herbaceous plant it touches. Use only aquatic formulations of glyphosate because they do not harm fish and other aquatic species.

The frequency of cattail removal can vary. Several factors influence the need to apply herbicide to cattails: the density at which the wetland is planted with desirable species, the time of year the wetland is planted, and the maturity of the wetland. During the first year or two after wetland construction, remove cattails twice a year. As the wetland matures and desirable species begin to dominate, reduce the maintenance frequency to once a year. The amount of time needed to remove unwanted vegetation (via the glyphosate wipe) varies, but a well-maintained, mature wetland requires visits of about 2 hours per acre of wetland.

Other unwanted plant species include common reed (*Phragmites* species, Figure 6), various noxious floating aquatics (such as parrot feather, *Myriophyllum aquaticum,* and giant salvinia, *Salvina* spp.), and Asiatic dayflower (*Murdannia keisak*). *Phragmites* species can be removed in a manner similar to that described for cattails. Noxious floating aquatics may require careful chemical or physical removal. If you observe these exotic invasive species, contact your county Extension center.

MOW THE PERIMETER OF WET PONDS

Stormwater wetlands are not mowed to the water's edge and tend to be surrounded by mature grasses. As a result, mowing the perimeter of wetlands is not a typical stormwater wetland maintenance activity. Many wet ponds, however, do have a grassed perimeter that needs to be maintained. Mowing maintenance is almost purely aesthetic. The type of grass used, its growing season, and pond aesthetics dictate the height and frequency of mowing:

- Mow cool-season grasses to a recommended height of 4 inches and no lower than 2.5 inches. Cool-season grasses, such as fescue, tend to be used west of Interstate 95 in North Carolina.
- Mow warm-season grasses to a recommended

height of 2.5 inches and no lower than 1.5 inches. Warm season grasses include centipede, Bermuda, and zoysia, and are principally found in eastern North Carolina.

- Mow every one to three weeks during the growing season when the wet pond is part of an accessible landscape or treated as an amenity.
- Mow wet ponds that are located out-of-sight once or twice a year.

The size and severity of slopes along the wet pond determine the type of mower to use. For small ponds, a standard push mower is often adequate. Larger ponds or ponds with steep banks will probably require a specialized pond mower.

Grass clippings can be left adjacent to the pond to provide organic matter that encourages grass to grow. Do not discharge grass clippings into the water, as this will encourage the growth of algae and could potentially clog the drawdown hole.

CONTROL PESTS

Rodents such as muskrats and beavers are attracted to stormwater wetlands and wet ponds (Figure 8). Once there, they can damage the stormwater management practice.

Figure 8. (A) Muskrat *(Ondatra zibethicus).* (B) Beaver *(Castor canadensis).* *(U.S. Fish and Wildlife Service)*

Figure 9. Muskrat holes along the perimeter of the wetland or wet pond are a sign of infestation. Destroying the holes is a simple way of forcing muskrats to move, if the population is limited.

Muskrats eat aquatic vegetation and burrow holes in the deeper pools. When muskrats actively burrow near the outlet of a wetland or wet pond, they will add sediment and increase turbidity to the outflow, increasing the release of pollutants from the wetland or wet pond. Moreover, muskrats will sometimes burrow holes around and through dams. These muskrat holes artificially lower the water level inside the pond or wetland, causing some plant species to die. At worst, the holes can lead to dam failure.

Beavers are attracted to the sound of running water. Once a beaver colonizes a wet pond or stormwater wetland, it will remove trees and shrubs surrounding the stormwater practice to build its lodge and dam. Beaver activity will clog or block the drawdown structure, thus raising the height of water inside the pond or wetland. This change in the depth of water inside wet ponds with aquatic shelves and stormwater wetlands will alter the types of vegetation that survive in the practice. Usually this change is undesirable.

Muskrat infestation is a difficult maintenance problem that usually must be addressed only when a pond or wetland has suffered from neglect. If the practice is infested, muskrats can be trapped under water, where they drown. Muskrats frequently escape traps, however, which makes live trapping difficult. Hire a licensed, experienced trapper who takes care to place traps where pets cannot be trapped by mistake. Once muskrats have been removed from the pond, their dwelling holes should be destroyed.

Keep Geese Away from Wet Ponds and Stormwater Wetlands

Canada geese are attracted to an open body of water with good visibility around the perimeter, and they enjoy eating grass. This describes many "old-design" wet ponds that are mowed to the edge, allowing geese easy access in and out of the pond. Designers can include features in a wet pond to prevent Canada geese from taking up residence:

- Build a visual barrier along the pond perimeter—the aquatic shelf. By taking away good visibility, geese will not feel as safe. Most newly designed ponds include some aquatic shelf.
- Place shiny objects, such as silver tape, around the perimeter of the pond if building an aquatic shelf is not feasible.
- Place a grid of string across the wet pond to prevent easy waterfowl water landing. This string can also have shiny tape attached to it (Figure 10).

You can also bring a dog to the pond regularly to scare the geese. Geese do not like certain species of dogs, particularly border collies. If they often encounter a frightening dog, the Canada geese will eventually move elsewhere.

Figure 10. A grid of fishing line adorned with silver tape has been strung across this wet pond to prevent geese from making it their home. The string grid makes water landing more difficult, and geese do not like shiny or flashy objects like windblown silver tape.

If the stormwater practice has been regularly maintained, muskrat populations can more easily be controlled. Encourage muskrats to move away from the wetland or wet pond by making it an uncomfortable place to live. If muskrat holes are observed around the perimeter of a wet pond or stormwater wetland, destroy them or fill them with soil (Figure 9). Identify and destroy muskrat holes during any regular maintenance activity: whenever the wetland or pond is being inspected to verify that the drawdown is freely flowing and during mowing and trash removal.

Removing beavers is more difficult that removing muskrats. If a beaver is observed living in or around a stormwater wetland or wet pond, contact a professional trapper who specializes in beaver removal.

SUMMARY

Well-designed stormwater wetlands and wet ponds remove pollutants and mitigate floods. To accomplish these goals and remain safe, aesthetically pleasing, and free of mosquitoes, they must be maintained properly to meet their design goals. Most stormwater wetland and wet pond maintenance activities are simple and inexpensive. But without them, the effectiveness of these stormwater management practices will decline.

TABLE 1. STORMWATER WETLAND AND WET POND MAINTENANCE TASKS AND FREQUENCIES

Task	Frequency	Notes
Remove sediment from forebay and deep pool (dredging/ dipping).	Varies. In stable watersheds, once every 5 to10 years is typical.	In unstable watersheds (those with active construction), the frequency increases to once a year, assuming the forebay is correctly sized.
Monitor sediment depth in forebay and deep pools.	Once a year.	In a large pond or wetland, a small boat may be needed.
Maintaining free-flowing orifice (drawdown hole).	Once per month and after every storm exceeding 2 inches.	Perform inspection regularly. Unclogging the hole when needed is simple.
Remove floating trash and debris.	Depends on design aesthetics: once a week to once a month.	Remove trash whenever the drawdown hole is being inspected. Inspect for trash more often if necessary, and remove as needed.
Remove vegetation from dam top and faces.	Once a year.	Dam top and faces should consist of mowed grass, if vegetated.
Remove invasive species (particularly cattails).	In years 1 and 2, twice a year (spring and fall). From year 2 onward, once a year (spring).	If spread of cattails is somewhat limited, use the glyphosate-wipe method.
Mow the wet pond perimeter.	Depends on design aesthetics. Ranges from every 1 to 3 weeks to once a year.	Wet ponds that are a design amenity will require more frequent mowing (every 1 to 3 weeks).
Remove muskrats and beavers.	Muskrat hole inspection and destruction should occur every time the wetland or wet pond is visited (at least once a month).	Contact a professional beaver trapper to remove beavers. Use muskrat traps to remove muskrats, or contact a professional trapper.

RESOURCES

Fact sheets in the Urban Waterways series, North Carolina Cooperative Extension, N.C. State University:

Hunt, W. F. *Urban Stormwater Structural Best Management Practices (BMPs*). AG-588-01.
Online: http://www.bae.ncsu.edu/stormwater/PublicationFiles/UrbanBMPs1999.pdf

Hunt, W. F., and B. A. Doll. *Design of Stormwater Wetlands for Small Watersheds.* AG-588-02.
Online:http://www.bae.ncsu.edu/stormwater/PublicationFiles/SWwetlands2000.pdf

Hunt, W. F., C. A. Apperson, and W G. Lord. *Mosquito Control for Stormwater Facilities*. AG-588-04.
Online: http://www.bae.ncsu.edu/stormwater/PublicationFiles/Mosquitoes2005.pdf

Hunt, W. F., and W.G. Lord. *Bioretention Performance, Design, Construction, and Maintenance*. AGW-588-05.
Online: http://www.bae.ncsu.edu/stormwater/PublicationFiles/Bioretention2006.pdf

Rodewald, A. D. *Nuisance Canada Geese: How to Deal with the Problem*. Ohio State University Extension publication no. W-3-2001.
Online: http://ohioline.osu.edu/w-fact/003.html

BAE Stormwater Group Web site:
www.bae.ncsu.edu/stormwater
Obtain information on upcoming workshops (including BMP Inspection and Maintenance Certification Courses), publications, PowerPoint presentations, images to download, and design and construction specifications.

State of North Carolina Stormwater Web site:
www.ncstormwater.org

ACKNOWLEDGEMENTS

All photographs were provided by the Department of Biological & Agricultural Engineering at N.C. State University except as noted for Figures 7 and 8.

Recommendations for the use of agricultural chemicals are included in this publication as a convenience to the reader. The use of brand names and any mention or listing of commercial products or services in this publication does not imply endorsement by North Carolina Cooperative Extension nor discrimination against similar products or services not mentioned. Individuals who use agricultural chemicals are responsible for ensuring that the intended use complies with current regulations and conforms to the product label. Be sure to obtain current information about usage reulations and examine a current product label before applying any chemical. For assistance, contact your county Cooperative Extension agent.

Prepared by
William F. Hunt, Ph.D., P.E.
Assistant Professor and Extension Specialist
Biological and Agricultural Engineering
North Carolina State University
and
Bill Lord
Area Environmental Agent
North Carolina Cooperative Extension

Published by
NORTH CAROLINA COOPERATIVE EXTENSION SERVICE

COLLEGE OF
AGRICULTURE & LIFE SCIENCES
ACADEMICS ▲ RESEARCH ▲ EXTENSION

NC STATE UNIVERSITY

AGW-588-07

E07-45831
08/2006/bs

APPENDIX H

Cistern – Additional Information - Water Budget Model

Rainwater Harvester 1.0

User Manual

Developed by: Matthew Jones
BAE Stormwater Engineering Group
Biological and Agricultural Engineering Department
North Carolina State University

NCSUWaterHarvesting@gmail.com

Overview

The Rainwater Harvester model simulates the performance of a rainwater harvesting system, using historical rainfall data to evaluate a daily water balance. The model is intended to assist designers in sizing a rainwater harvesting cistern based upon rainfall inputs and anticipated usage.

General Operating Instructions

1. Load rainfall data file
2. Input system design values
3. Change tab to "Water Usage" and input usage values
4. Click "Simulate" button at lower right
5. View system performance summary data
Optional:
6. Click "Animate" button to view a visual representation of the cistern level over time
7. Save the simulation results to a comma-separated variable (.csv) file

Inputs

System Configuration

Rainfall Input File:

Rainfall input files for several North Carolina cities are available from the NCSU rainwater harvesting website. The file can have a ".rai" or ".csv" extension with the data formatted as comma-separated variables with the following data columns:

- Index Day *(Beginning with 1/1/1900 as day 1)*
- Year
- Month
- Day
- Rainfall (in 1/100ths of an inch)

Roof Area:

Horizontal footprint of the roof area contributing runoff to the cistern

Capture Factor:

This factor represents the ratio of rainfall depth that is captured by cistern. Research from USARS suggests a ratio of 0.9, the model's default value. Research at NCSU has shown that this factor can be dramatically reduced if gutters aren't kept free of leaves or an inlet filter on the cistern restricts flow.

City:

Selecting a city from the list loads the default values for water cost and nitrogen concentration.

Water Cost:

The cost of a gallon of water from municipal sources

Nitrogen Concentration:

The typical concentration of nitrate and ammonia in rooftop effluent

First Flush Depth:

Depth of rainfall containing the most polluted runoff. Values vary by region, but typically range from 0.5" to 1.5"

Cistern Size:

Cistern volume in gallons

Cistern Cost:

The cost of the rainwater harvesting system and installation

Table 1: Example cost estimates for a variety of cisterns

Cistern Volume	Plastic	Metal
100 gallons	$300	--
500 gallons	$500	$1400
1,000 gallons	$900	$2200
5,000 gallons	$2100	$5200
10,000 gallons	$5000	$7700

Water Usage

Importance of Water Usage Information:

In order for the model to closely simulate the performance of a rainwater harvesting system, accurate water usage data is essential. Ideally, water usage measurements should be collected at the location where the rainwater harvesting system will be installed. These usage estimations can be collected with a variety of inexpensive flow metering devices.

Table 2: Typical water usage that could be replaced with harvested rainwater

Usage	Frequency	Volume
Irrigating Established Lawn	Once per week	62 gal. / 100 ft^2
Home Car Wash	--	50 – 100 gal.
Professional Car Wash	--	~ 20 gal.

Daily Usage:
Gallons per day that are used consistently on a day-to-day basis

Seasonal Usage:
Gallons per day evaluated each week during the specified months

Toilet Usage:
Estimated toilet usage based upon 5 uses per individual per day

Weekend Usage:
If checked, the model will include toilet usage during all 7 days of a week

Outputs

Total Volume Captured:
Percentage of total runoff volume the cistern was able to capture without overflow

Usage Replaced:
Percentage of total water demand that the cistern was able to supply

Note: The total volume captured and usage replaced serve as quick indicators of how well the cistern performs with regards to water quality and water supply

Annual Water Usage:
Average amount of water used from the cistern in a given year

Annual Water Savings:
Average amount of monetary savings from using the cistern to replace municipal water supply

Overflow Frequency:
Percentage of rainfall events that resulted in overflow from the cistern

Dry Cistern Frequency:
Percentage of days when there was a water demand, but not enough water stored in the cistern to meet that demand

First Flush Volume Captured:
Percentage of runoff volume associated with the first flush rainfall depth that the cistern was able to capture without overflow

Annual Nitrogen Removed:
Weight of nitrogen removed from runoff, assuming that all nitrogen captured by the cistern is removed via the cistern itself or subsequent water usage

Payback Period:
Number of years of water use required for total water savings to equal the cost of the cistern

Model Assumptions

- When calculating the daily water balance, the model first adds rainfall inputs, then subtracts the daily water usage
- Cost estimates are based upon local city water costs from 2005 and do not include sewer costs, which are often based upon water usage
- Calculation of pay return period is a simple calculation that does not account for interest rates or changes in water cost over time
- Total nitrogen captured by the cistern is assumed to be removed through denitrification within the cistern or subsequent water usage. Denitrication within the cistern may be minimal; however, using the water for toilet flushing or irrigation effectively reduce or eliminate the nitrogen loading to surface waters.

Troubleshooting

- ***Problem*:**
  - I receive an error about the .NET Framework or the program won't open
- ***Solution*:**
  - Check in the "add or remove programs" area of the windows control panel to see if you have the .NET Framework installed. The .NET Framework is often installed with windows updates, but can be manually installed from: http://www.microsoft.com/downloads/details.aspx?familyid=0856eacb-4362-4b0d-8edd-aab15c5e04f5&displaylang=en

- ***Problem:***
  - I accidentally changed or deleted an input file
- ***Solution:***
  - The input data files can be extracted and manually copied from the .zip file located on the NCSU rainwater harvesting website

- ***Problem*:**
  - I receive an error when trying to save the output to a network folder
- ***Solution*:**
  - Currently, output files can only be saved to local drives and then copied to network folders

- ***Problem:***
  - My output values don't seem reasonable
- ***Solution:***
  - If using custom rainfall data, ensure that the input data file is in the correct format

APPENDIX I

Pump Sizing Information for Cisterns

URBAN Waterways

Choosing a Pump for Rainwater Harvesting

INTRODUCTION

Water harvesting is the practice of capturing rainwater runoff, normally from a rooftop, and storing it in a tank or cistern for use around a home or business. While gravity flow from a cistern is generally enough to fill a bucket or to water a few nearby plants, most water-harvesting systems require a pump to convey the water from the holding tank to the spot where it will be used (Figure 1). Typical uses include watering plants, washing vehicles, flushing toilets, and washing clothes. A pump can increase the uses of the water-harvesting system and is required when consistent pressure is needed. Knowledge of how pumps operate and how they are selected will ensure that an efficient and appropriate pump is included in the water-harvesting system design.

Because pumps and plumbing systems are diverse, people installing water-harvesting systems should consult an experienced plumber to make sure all applicable codes are met and that there will be no damage to the pump or plumbing. Pump selection should be based on the flow and total head the pump is required to supply. Flow is the rate at which water travels through a pipe and often is measured in gallons per minute (gpm). Total

Figure 1. Pump with pressure tank before installation and example of system in use

Distributed in furtherance of the Acts of Congress of May 8 and June 30, 1914. North Carolina State University and North Carolina A&T State University commit themselves to positive action to secure equal opportunity regardless of race, color, creed, national origin, religion, sex, age, or disability. In addition, the two Universities welcome all persons without regard to sexual orientation. North Carolina State University, North Carolina A&T State University, U.S. Department of Agriculture, and local governments cooperating.

NC STATE UNIVERSITY A&T STATE UNIVERSITY COOPERATIVE EXTENSION
Helping People Put Knowledge to Work

head is a description of the energy required to move the water and is typically expressed in feet of water or pounds per square inch (psi). This publication reviews the pump selection process and at the end provides a sample calculation of flow and total head.

When properly configured, a rainwater-harvesting system delivers many benefits, including reduced flooding, improved water quality, reduced demand on a well or city water supply, and monetary savings. For more information on water-harvesting systems, see *Permeable Pavements, Green Roofs, and Cisterns: Stormwater Practices for Low Impact Development*, AG-588-06, part of the *Urban Waterways* series.

PUMP TYPES

Pumps can be divided into two major categories: positive displacement pumps and dynamic pumps.

Positive displacement pumps operate by mechanically moving water by means of the action of a gear or piston and are able to produce high heads, but relatively low flows. They are generally used in hydraulic systems and in a number of specialty applications. Typical positive displacement pumps are piston and rotary pumps.

Dynamic pumps provide a continuous flow by developing a high fluid velocity and are able to produce high flows, but relatively lower heads. They are used to satisfy most general pumping requirements and typically require less maintenance than displacement pumps. Typical dynamic pumps include centrifugal and jet pumps.

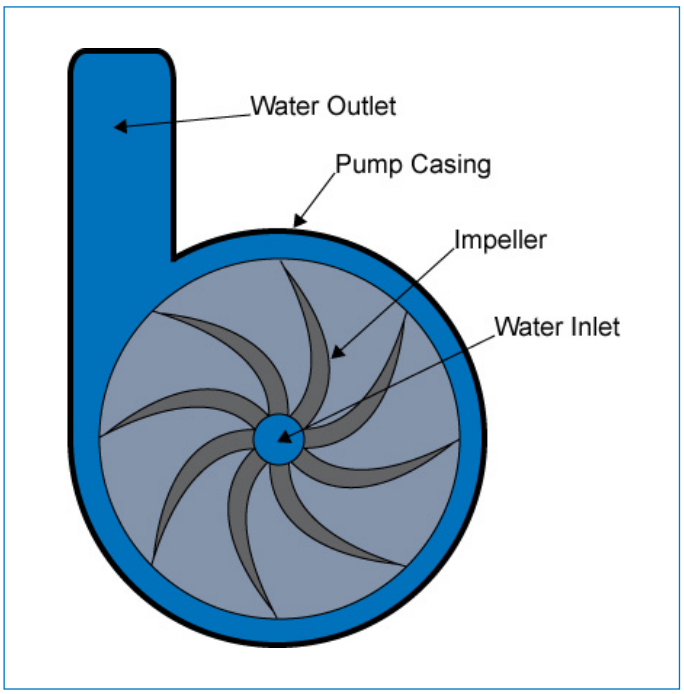


Figure 2. Centrifugal pump

A centrifugal pump is suitable for most water-harvesting applications because of its relative simplicity, range of head and flows, and relative low cost. A centrifugal pump consists of a motor, pump casing, and impeller (Figure 2). The pump casing holds the impeller and channels water to and from the impeller. The impeller is a rotating vane structure that draws water into the pump casing, transfers energy to the water, and discharges it from the pump casing. The motor supplies the energy needed to rotate the impeller. For a specific pump casing, the motor and impeller often can be sized to meet head and flow requirements.

When a pump is installed above a cistern, problems with priming the pump and maintaining the prime arise. For this reason, either a submersible pump should be installed toward the bottom of the cistern, or a plumber should be consulted for specific pump requirements.

CALCULATION OF PUMP DEMAND

Flow

The flow for a pump system is determined by adding the flows of all fixtures, such as toilets, washing machines, sprinklers, etc., that may draw water from the cistern at the same time. For example, if a lawn needs to be watered with an impact sprinkler and a toilet is flushed while the sprinkler is running, the flows should be added for both uses. Table 1 contains typical flows for common fixtures. Specific flows for many devices can be found in the product literature and should be used in calculations when available.

Head

The "head" required of the pump is determined by calculating the total dynamic head of the system.

Equation 1. Total Dynamic Head (TDH)

$$TDH = h_p + h_e + h_f$$

TDH = total dynamic head (ft)

h_p = operating head (pressure) required by fixture (ft)

$h_e = h_2 - h_1$ = elevation difference between pump and fixture (ft)

h_f = friction loss in system (ft)

When the cistern feeds multiple fixtures, the total dynamic head should be calculated independently for each fixture. Because total dynamic head is not cumulative, the specifications for the fixture that demands the most head should be used in pump selection.

Table 1. Typical minimum requirements of common fixtures in water-harvesting.

Use	Pressure (ft)	Pressure (psi)	Flow
Impact sprinkler	93	40	4.5 gpm
Clothes washer	46	20	5 gpm
Pressure washer	46	20	4 gpm
Toilet	46	20	6 gpm
Garden hose nozzle	81	35	5 gpm

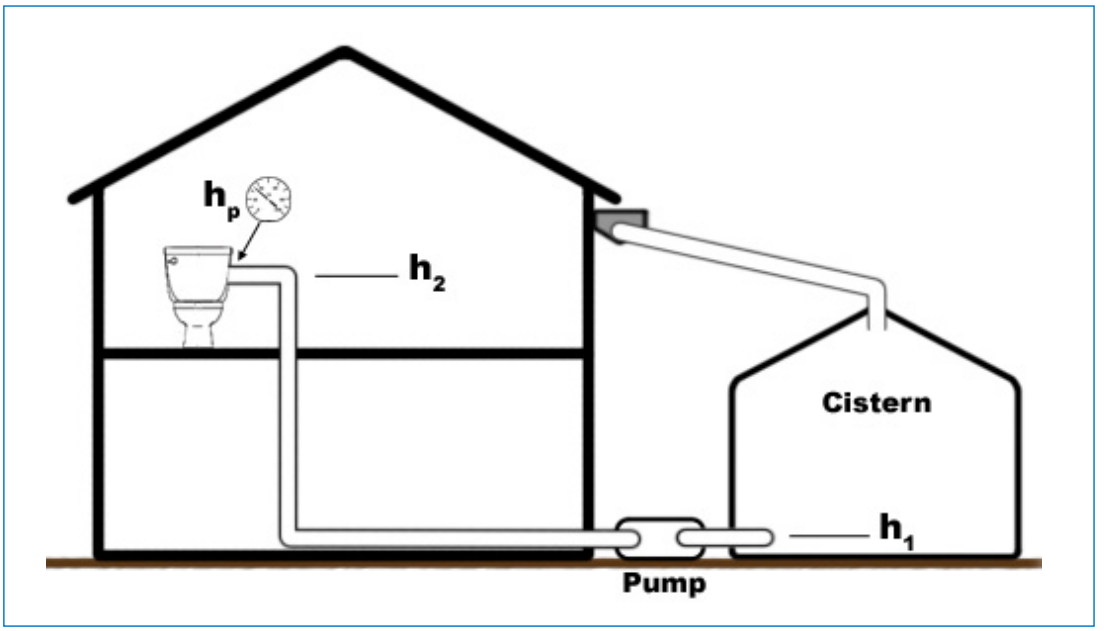


Figure 3. Graphic representation of the terms in Equation 1.

Pressure: H_p The term "pressure" corresponds to the pressure required at the outlet to operate whatever device is being used. Typical minimum operating pressures for a number of devices are found in Table 1. For specific pressure requirements, consult the product literature. Equation 2 can be used to convert pressures in psi to feet of head. If the pressure selected is too low, the pump may not provide an adequate flow to operate the device; on the other hand, if an extremely high pressure is selected, it could damage seals and other plumbing equipment. The 2002 North Carolina state building code specifies that a water distribution system should not leak when tested at 100 psi.

Equation 2: Pressure Conversion

Feet of Head = PSI x 2.31

Elevation: H_E The term "elevation" corresponds to the vertical distance water must be lifted to reach the location where it will be used. This distance is measured from the pump intake (h_1) to the water outlet (h_2) (Figure 3).

Friction: H_F "Friction" accounts for energy losses associated with moving water through a plumbing network. The primary components are energy loss due to friction with the pipe walls and losses through elbows, valves, and other fittings. Manual calculation of friction is a complex process; therefore, information on typical friction losses for common pipe diameters is included in Tables 2 and 3.

Friction loss due to pipe fittings can be calculated by using what is known as the equivalent length method. Look up the equivalent pipe length for the appropriate diameter of each fitting in Table 3. Add the equivalent lengths for all fittings encountered between the pump and the intended fixture for use in Equation 3.

To calculate the friction loss within the pipe, first find the friction factor (F_{100}) that corresponds to the flow and pipe diameter of the plumbing in Table 2. Next, find the total linear distance of pipe that water must travel from the pump to the intended fixture. Use the calculated values in Equation 3 to determine the total friction loss.

TABLES FOR USE IN FRICTION LOSS CALCULATIONS

Table 2. Friction loss for every 100 linear feet of schedule 40 PVC pipe (units: feet of head).

	Pipe Diameter (in.)							
Q (gpm)	**1/2**	**3/4**	**1**	**1 1/4**	**1 1/2**	**2**	**2 1/2**	**3**
2	5.752	1.302	0.390	0.111	0.052	0.015	0.006	0.002
4	19.307	4.346	1.294	0.365	0.170	0.050	0.021	0.008
6	39.437	8.850	2.627	0.739	0.343	0.100	0.041	0.015
8	Excessive Velocities	14.697	4.355	1.222	0.567	0.165	0.068	0.025
10		21.811	6.455	1.808	0.838	0.244	0.100	0.037
15			13.234	3.697	1.710	0.496	0.203	0.075
20				6.156	2.845	0.823	0.337	0.124
25				9.154	4.227	1.222	0.500	0.183

Table 3. Equivalent length for pipe fittings (units: feet of pipe length).

	Pipe Diameter (in.)							
Fitting	**1/2**	**3/4**	**1**	**1 1/4**	**1 1/2**	**2**	**2 1/2**	**3**
90° Elbow	1.5	2.0	2.5	3.8	4.0	5.7	6.9	7.9
45° Elbow	0.8	1.1	1.4	1.8	2.1	2.6	3.1	4.0
Open Gate Valve	0.3	0.4	0.6	0.8	1.0	1.5	2.0	3.0
Tee – Straight Flow	1.0	1.4	1.7	2.3	2.7	4.3	5.1	6.2
Tee – Branch Flow	4.0	5.0	6.0	7.0	8.0	12.0	15.0	16.0

(Tables 2 and 3 adapted from www.engineeringtoolbox.com)

Equation 3. Friction loss in system

$h_f = [(L_P + L_F) / 100] \times F_{100}$

F_p: Friction head loss (ft)

L_P: Linear length of pipe (ft)

L_F: Equivalent length for pipe fittings (ft)

F_{100}: Friction loss per 100 feet of pipe from Table 2 (ft)

If the calculated friction loss is very high, it may be necessary to consider using pipes of larger diameter to prevent damage to the pump or plumbing system. A rule of thumb is to limit the water velocity in the pipes to 7.5 feet per second or less. If water will be pumped through a filter, the head loss through the filter should be included with the friction term. Because head loss due to filtration varies depending on the type of filter being used and the flow rate, the filter product literature must be consulted for specific head losses.

HOW TO SELECT A SPECIFIC PUMP

Once the required flow and total dynamic head are determined, a pump vendor can be consulted for information on specific pumps that are best suited for system demand. If a designer wishes to select his/her own pump or to understand why a vendor recommends a specific pump, knowledge of "pump curves" is required (Figure 4). A pump curve provides a description of pump performance and can be obtained from a pump manufacturer or vendor.

While the publication of pump curves varies, depending on the source, the most common curve is the head/flow curve. This curve illustrates what flow the pump will supply for a given head requirement. The pump is designed to operate at a point somewhere along this curve. It is important that the target head and flow lie either on or below this curve. If the target head and flow lie above and to the right of this curve, the pump will not be able to supply enough water to meet design requirements. For best overall efficiency, the target discharge should be in the middle third of the curve.

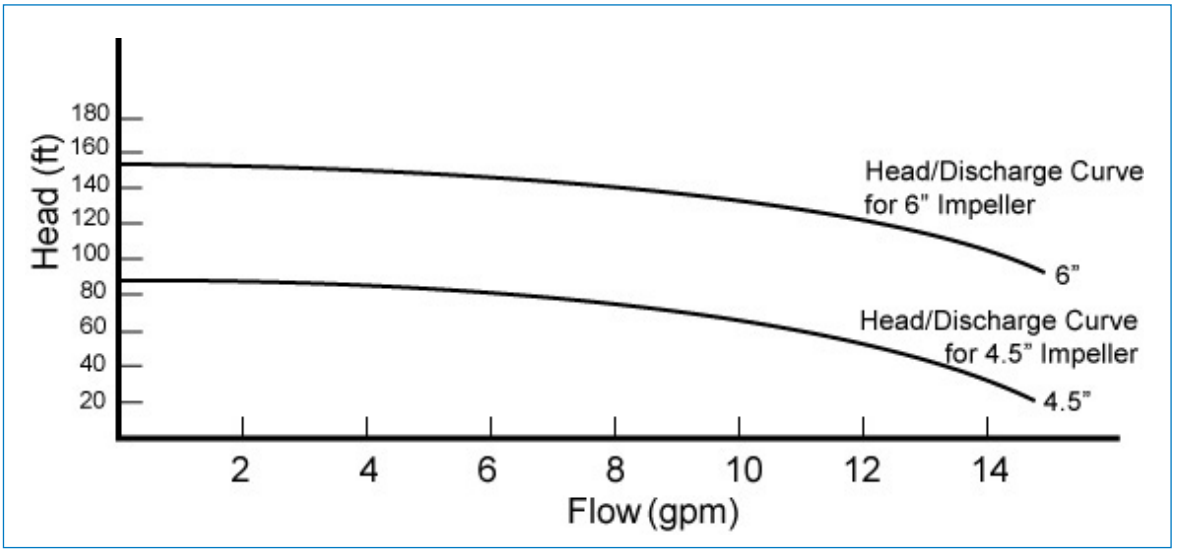


Figure 4. **Example of a pump curve with 2 impeller options.**

PUMP ACCESSORIES

Depending on the water-harvesting application, some pump accessories may be needed. Consult a pump vendor to determine which accessories are necessary and compatible with a specific pump.

PRESSURE TANK – The tank stores pressurized water to prevent the pump from cycling on and off to meet small demands; it also supplies a constant pressure.

PRESSURE SWITCH –This device engages the pump when a pressure drop is observed and disengages it when there is no demand. For example, the pump will engage to supply water when a faucet is opened and disengage when no water is being used.

CHECK VALVE – The internal check valve prevents water from flowing back through the pump when it is not running. Some pumps do not have these valves. Consult a pump vendor or plumber to determine if additional check valves are needed.

FLOAT LEVEL SWITCH – This switch, when installed in the cistern, can prevent damage to the pump by disengaging the pump when the cistern runs dry or cistern water falls below a predetermined level.

THROTTLING VALVE – This device is intended to control the flow and pressure of water exiting the pump and is typically in the form of a gate valve. Special control systems can be installed to maintain a constant output despite changing water levels within a cistern.

EXAMPLE: CHOOSING A PUMP FOR A WATER-HARVESTING SYSTEM

An aboveground water-harvesting cistern is installed at a home in coastal North Carolina. The cistern will be used to flush a toilet on the second floor of the home and to run an impact sprinkler for the lawn. All pipes in this example are ¾ inches in diameter. Select a pump that meets the needs shown in Figure 5.

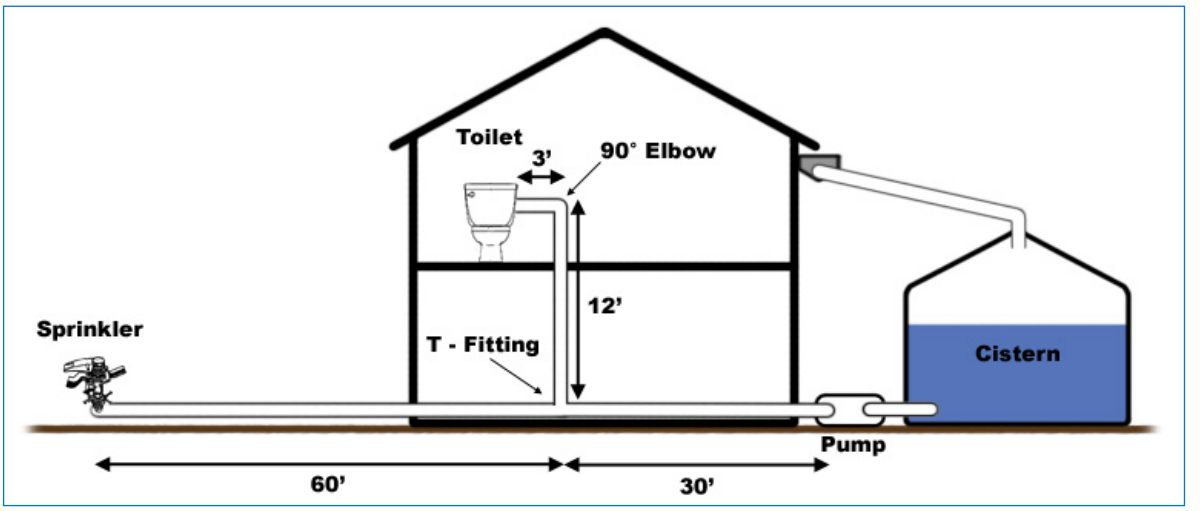


Figure 5. Example of a simple water-harvesting system.

Required Flow

From *Table 1**, the required flow is 6 gpm for the toilet and 4.5 gpm for the impact sprinkler. It may be necessary to operate both fixtures at the same time; therefore:

Total Peak Flow = 6 gpm + 4.5 gpm = **10.5 gpm**

Required Total Dynamic Head

Because there are 2 fixtures for this system, the required total dynamic head for each fixture must be calculated independently.

Toilet

$h_e = h_2 - h_1$ = 12 ft *(from Figure 5)*

h_p = 46 ft *(Table 1)*

Friction

L_F = 5.0 *(3/4" Tee – Branch Flow, Table 3)* + 2.0 *(3/4" 90° Elbow, Table 3)* = 7.0 ft

L_P = 30 + 12 + 3 = 45 ft *(Adding lengths of pipe segments)*

h_f = [(45 + 7.0) / 100] x 8.85 *(Friction factor for ¾" pipe at 6 gpm , Table 2)* = 4.6 *(Equation 3)*

Total Head Requirement = 12 + 46 + 4.6 = **62.6 ft** *(Equation 2)*

Impact Sprinkler

$h_e = h_2 - h_1$ = 0 ft *(from Figure 5)*

h_p = 93 ft *(Table 1)*

Friction

L_F = 1.4 ft *(3/4" Tee – Straight Flow, Table 3)*

L_P = 30 + 60 = 90 ft *(Adding lengths of pipe segments)*

h_f = [(90 + 1.4) / 100] x 8.85 = 8.1 *(Equation 3)*

Total Head Requirement = 0 + 93 + 8.1 = **101 ft** *(Equation 2)*

Because the impact sprinkler has a higher head requirement than the toilet, the impact sprinkler head value will be used for the pump design.

Two pump curves are shown in Figure 6. Find the design point by locating the intersection of the required head and flow, denoted by the "x" in the graph. Notice that the design point lies above the curve for the 4.5" impeller; therefore, that impeller size will not meet the system demand. The design point lies below the curve for the 6" impeller, indicating the 6" impeller will provide an adequate water supply. Because the 6" impeller can supply the required head and flow, this pump will satisfy the demands of this water-harvesting system.

*Sources for numbers are noted by *blue italics*.

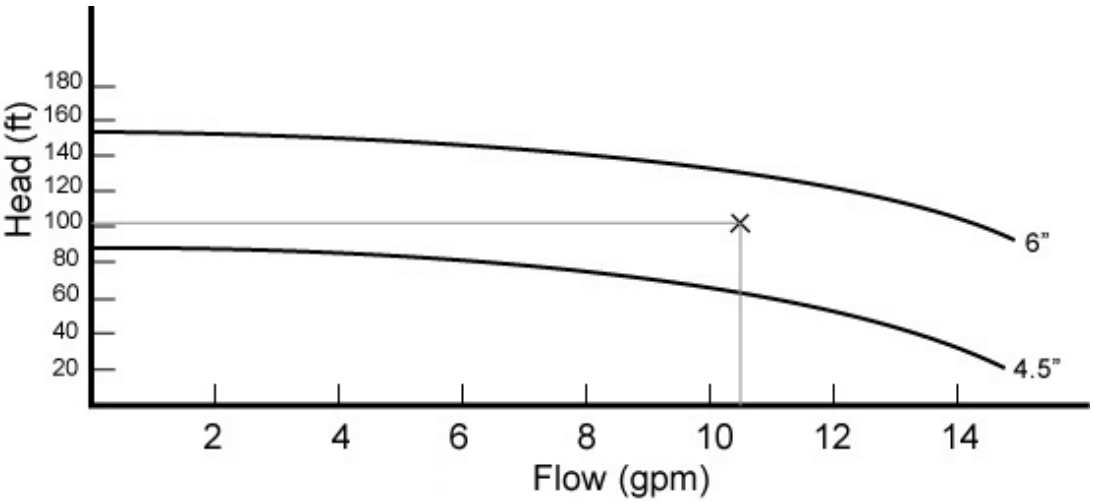


Figure 6. The pump's design point is at "x," the intersection of the required head and flow.

INTERNET RESOURCES

2002 North Carolina State Building Code
http://www.ncdoi.comOSFM/Engineering/engineering_home.asp

Engineering Tool Box
www.engineeringtoolbox.com

North Carolina State University —
Biological and Agricultural Engineering Stormwater Group
www.bae.ncsu.edu/stormwater

State of North Carolina Stormwater Home Page
www.ncstormwater.org

Texas A&M Rainwater Harvesting
http://rainwaterharvesting.tamu.edu/

***Urban Waterways series: Permeable Pavement, Green Roofs, and Cisterns: Stormwater Practices for Low Impact Development*, AG-588-06**
http://www.bae.ncsu.edu/stormwater/Publication Files/BMPs4LID.pdf

Water Harvesting at North Carolina State University
www.bae.ncsu.edu/topic/waterharvesting

Prepared by

Matthew P. Jones, E.I.
and
William F. Hunt, P.E., Ph.D.
Biological and Agricultural Engineering
North Carolina State University

Copyright © 2006 by North Carolina State University

Published by
NORTH CAROLINA COOPERATIVE EXTENSION SERVICE

COLLEGE OF
AGRICULTURE & LIFE SCIENCES
ACADEMICS ▲ RESEARCH ▲ EXTENSION

NC STATE UNIVERSITY

AG-588-08

E07 45836
10/06—JL

APPENDIX J

Nomograph For Use In Solving The Manning Equation For Trapezoidal Channels
From the Draft Iowa Stormwater Management Manual (www.ctre.iastate.edu/PUBS/stormwater/)

Trapezoidal solution nomograph. The trapezoidal channel nomograph solution to Manning's equation in Figure 10 can be used to find the depth of flow if the design discharge is known or the design discharge if the depth of flow is known:

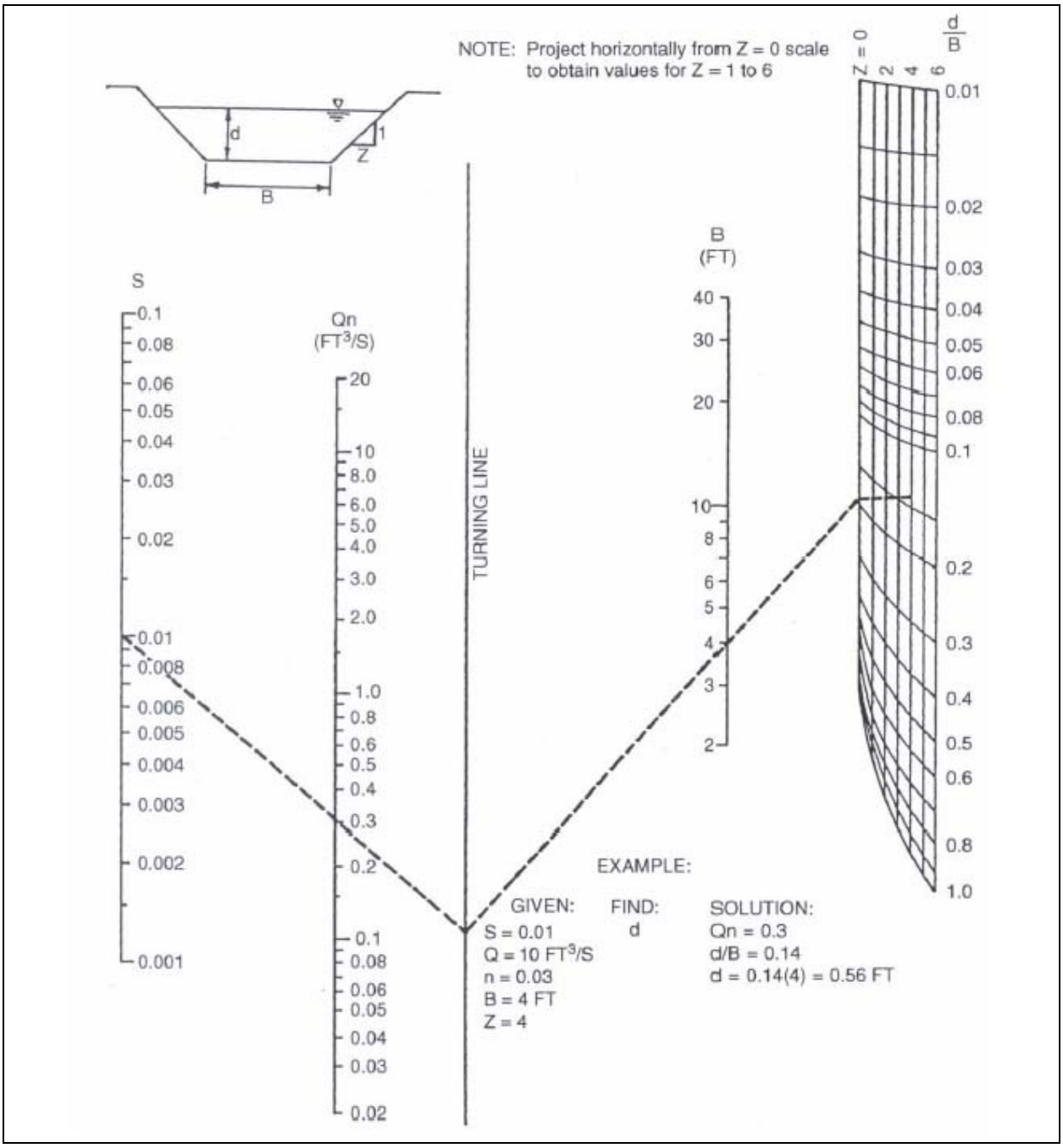
a. Determine input data, including slope in feet per feet, Manning's n value, bottom width in feet, and side slope in feet per feet.

b. Given the design discharge, do the following:

   1) Find the product of Q times n, connect a line from the slope scale to the Qn scale, and find the point of intersection on the turning line.
   2) Connect a line from the turning point from Step b1 to the b scale, and find the intersection with the z=0 scale.
   3) Project horizontally from the point located in Step b1 to the appropriate z value, and find the value of d/b.
   4) Multiply the value of d/b obtained in Step b3 by the bottom width b to find the depth of uniform flow, d.

c. Given the depth of flow, do the following:

   1) Find the ratio d divided by b, and project a horizontal line from the d/b ratio at the appropriate side slope, z, to the z=0 scale.
   2) Connect a line from the point located in Step c1 to the b scale and find the intersection with the turning line.
   3) Connect a line from the point located in Step c2 to the slope scale and find the intersection with the Qn scale.
   4) Divide the value of Qn obtained in Step c3 by the n value to find the design discharge, Q.


NOTE: Project horizontally from Z = 0 scale to obtain values for Z = 1 to 6
d
1
Z
B
S
0.1
0.08
0.06
0.05
0.04
0.03
0.02
0.01
0.008
0.006
0.005
0.004
0.003
0.002
0.001
Qn
(FT3/S)
20
10
8.0
6.0
5.0
4.0
3.0
2.0
1.0
0.8
0.6
0.5
0.4
0.3
0.2
0.1
0.08
0.06
0.05
0.04
0.03
0.02
TURNING LINE
B
(FT)
40
30
20
10
8
6
5
4
3
2
Z = 0
2
4
6
d/B
0.01
0.02
0.03
0.04
0.05
0.06
0.08
0.1
0.2
0.3
0.4
0.5
0.6
0.8
1.0
EXAMPLE:
GIVEN:
S = 0.01
Q = 10 FT3/S
n = 0.03
B = 4 FT
Z = 4
FIND:
d
SOLUTION:
Qn = 0.3
d/B = 0.14
d = 0.14(4) = 0.56 FT